2ND *Edition*

Cardiographic Technique

A Schott MD *(Heidelberg)* MRCS
E H Snell AMIEE

A manual for cardiological technicians

William Heinemann Medical Books Ltd London

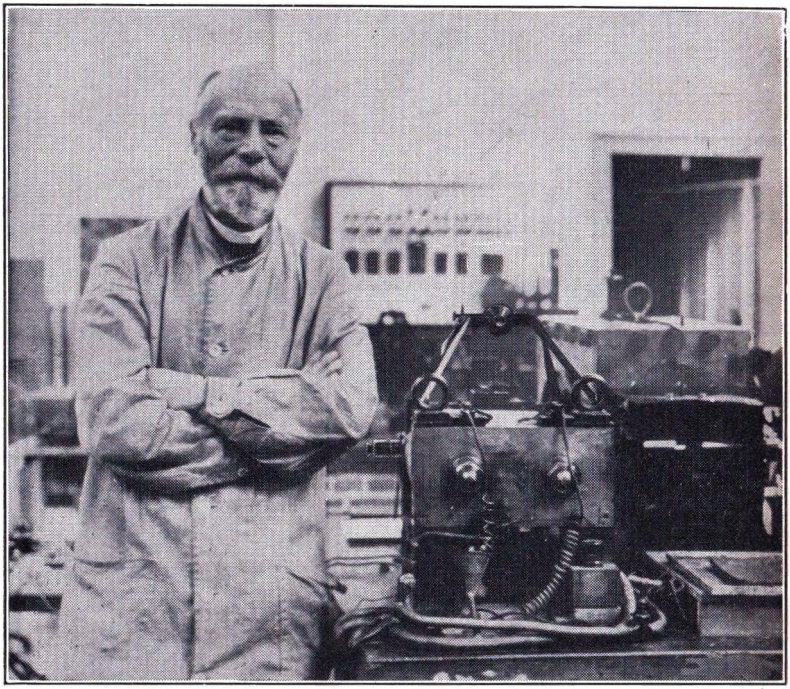
The object of the second edition of this manual remains the same as that of the first: to describe for cardiological technicians the fundamental principles, biological as well as instrumental, on which electrocardiography and phonocardiography are based. Such informed approach will not only improve the quality of their work, but also greatly add to their interest in carrying it out.

The biological foundation and the physical principles of the recording instruments, on which electro- and phonocardiography rest, are described; and the technique is detailed which should be employed to obtain accurate records, including the recognition and elimination of common faults. This supplements and amplifies the operating instructions given by manufacturers of the equipment.

Though the object of the manual has remained unchanged since the publication in 1952 of the first edition (by S. L. Barron and A. Schott), advances in the subject have been so great that it has proved necessary to rewrite the text almost completely. Furthermore, with a few exceptions new illustrations have been used. This second edition is thus largely a new book rather than a revised version of its predecessor.

25s
net

CARDIOGRAPHIC TECHNIQUE



W. Einthoven in his laboratory at Leyden with his original string galvanometer.

CARDIOGRAPHIC TECHNIQUE

A MANUAL FOR CARDIOLOGICAL TECHNICIANS

BY

A. SCHOTT, M.D. (Heidelberg), M.R.C.S.

Physician in Charge, Cardiological Department,
Queen Mary's Hospital for the East End, London

AND

E. H. SNELL, A.M.I.E.E.

SECOND EDITION

WILLIAM HEINEMANN MEDICAL BOOKS LIMITED
LONDON

First Edition, 1952
Second Edition, 1963
Reprinted, 1965

© by A. Schott and E. H. Snell, 1963
All rights reserved

PRINTED IN GREAT BRITAIN BY THE WHITEFRIARS PRESS LTD.
LONDON AND TONBRIDGE

PREFACE TO THE SECOND EDITION

SINCE the publication in 1952 of the first edition of this book by S. L. Barron and one of us (A. S.), advances in the subject have been so great that it has proved necessary to rewrite the text almost completely. Furthermore, with few exceptions new illustrations have been used. This second edition is thus largely a new book, rather than a revised version of its predecessor.

London 1963.

A. S.
E. H. S.

ACKNOWLEDGEMENTS

WE should like to express our gratitude to Dr. Aubrey Leatham, F.R.C.P., Physician, St. George's Hospital and National Heart Hospital, London, for kindly allowing us the use of his department, and to his Chief Technician, Mr. J. G. Davies, F.S.C.T., for recording the phonocardiograms reproduced in Figs. 11.1, 11.2 and 11.3.

We are grateful to the following for permission to reproduce illustrations:

Akademiai Kiado, Budapest, for Figs. 3.3a and b, from *Atlas of Human Anatomy* by Kiss and Szentágothai; E. & S. Livingstone Ltd., for Fig. 3.5a, from *Basic Anatomy* by Mitchell and Patterson; Oxford University Press for Fig. 3.5b, from *Textbook of Anatomy* by Cunningham, 9th edition; Fretz and Wasmuth, Zurich, for Fig. 3.15, and the same publisher and also Georg Thieme, Stuttgart, for Fig. 13.10, from *Klinische Elektrokardiographie* by Holzmann, first and fourth editions respectively; McGraw-Hill Book Company for Fig. 3.16, from *Electrophysiology of the Heart* by Hoffman and Cranefield; American Heart Association Inc., for Figs. 13.1 and 13.7, from the article by E. Frank in *Circulation* (1954), **10,** 101; J. Springer, Berlin, for Figs. 13.2 and 13.9, from the article by F. Schellong in *Erg. inn. Med. Kinderheilk.* (1939), **56,** 657; Henry Kimpton for Figs. 13.3, 13.4 and 13.5, from *Spatial Vectorcardiography* by Burch, Abildskov and Cronvich; W. B. Saunders Company for Fig. 13.6, from *Spatial Vectorcardiography* by Grishman and Scherlis.

We are also grateful to the following firms for the blocks for illustrations: Philips Electrical Ltd., Fig. 5.9; Sierex Ltd. (Elema-Schönander), Fig. 5.10; The Cambridge Instrument Co. Ltd., London, Figs. 6.7, and 14.2; Cardiac Recorders Ltd., Fig. 6.8; Electronic and X-Ray Applications Ltd. (Sanborn), Fig. 6.9.

We are also indebted to The Cambridge Instrument Co., Inc., New York, for the Frontispiece; and for Figs. 14.1, 14.3, and 14.4.

Last, but by no means least, we should like to record our gratitude to the publishers, and in particular to Mr. J. Johnston Abraham and to Mr. Owen R. Evans, for the generous help and assistance they have given us in the preparation of this book.

A. S.
E. H. S.

CONTENTS

CHAPTER		PAGE
1	INTRODUCTION	1
2	HISTORICAL DEVELOPMENT	3
3	BIOLOGICAL ASPECTS	7
4	THE STRING ELECTROCARDIOGRAPH	42
5	VALVE-OPERATED CARDIOGRAPHS	45
6	TRANSISTOR-OPERATED CARDIOGRAPHS	62
7	TO TAKE AN ELECTROCARDIOGRAM	76
8	EXTRANEOUS INTERFERENCE AND COMMON FAULTS AND THEIR ELIMINATION	90
9	MOUNTING ELECTROCARDIOGRAMS	96
10	INDEXING AND FILING OF ELECTROCARDIOGRAMS AND REPORTS	99
11	PHONOCARDIOGRAPHY	104
12	PROCESSING PHOTOGRAPHIC RECORDS	116
13	THE VECTORCARDIOGRAM	120
14	SPECIAL CARDIOLOGICAL EQUIPMENT	129
	GLOSSARY	135
	INDEX	137

CHAPTER 1

INTRODUCTION

THE object of this manual is to describe for cardiological technicians the fundamental principles, biological as well as instrumental, on which electrocardiography * and phonocardiography are based. Such informed approach will not only improve the quality of their work, but also greatly add to their interest in carrying it out.

Understanding of the biological basis of electrocardiography entails a basic knowledge of the anatomy and physiology of the heart and of the mode of origin and conduction of heart action currents; that of phonocardiography, of the mode of origin of heart sounds and their time relation to the various phases of cardiac contraction and relaxation. From a more practical point of view, a better understanding of basic principles will enable technicians to recognise artefacts in records or defects in the recording instrument, to correct faults in the application of their technique and put right some minor instrumental defects. It will also reduce the risk of producing faulty records which, in some instances, may be so misleading as to result in wrong interpretation by the physician.

In some patients periodical examinations may extend over many years, and it is not at all rare that small variations in tracings of otherwise common forms are of great medical relevance. Comparison between tracings of the same patient taken at different times can be reliable only if *all* tracings are accurate; this is of paramount importance. Well-defined tracings are also necessary if they are to be published. Most publishers are unwilling or reluctant to accept retouched records which, from the scientific point of view, is a commendable practice.

Technicians may be, and often are, much handicapped in their work by inexperienced people—usually junior members of the medical staff —using or experimenting with the equipment in their charge. Instruments should be made available only to people known to be competent in their use, to others only in the technician's presence. Incompetent handling of apparatus is the commonest cause of their breakdown.

Electrocardiograms and phonocardiograms can only be interpreted in the context of clinical findings. Interpretation therefore necessitates

* Electrocardiograph(y) and cardiograph(y), and electrocardiogram (ECG) and cardiogram, respectively, are used as interchangeable terms in this book.

medical training, and it is thus undesirable that technicians should attempt to interpret records.

Physicians who take their own tracings should regard themselves as being technicians while doing so, and it is hoped that they will find some useful hints in the pages that follow.

It is not proposed to deal with any specific make of apparatus, as the underlying principles are common to all. Most manufacturers issue directions for operating their instruments and these will in time become rule-of-thumb operations. It is because much more is required of competent cardiographic technicians than the mere operation of controls that this work has been undertaken.

CHAPTER 2

HISTORICAL DEVELOPMENT

Electrocardiography deals with the recording of electrical currents produced by the heart when it contracts, and the beginning of its historical development may, therefore, be dated from the discovery in 1843 by Matteucci that in certain circumstances electrical currents occur in strips of heart muscles of pigeons.

In 1856, Kölliker and Müller showed that electrical changes occurred when an isolated frog heart contracted. Burdon-Sanderson and Page demonstrated in 1879–80 that every excited part of the surface of the ventricle of a frog heart was electrically negative compared with every unexcited part. In a later study (1883–84) they recorded photographically the electrical changes in the hearts of frogs and tortoises during excitation. That the electrical currents of the human heart can be recorded by electrodes placed on the surface of the body was shown in 1887 by A. D. Waller, who was thus the first to take an "electrocardiogram". However, the galvanometer which he used for registering the electrical currents was far too inaccurate to provide a true record. It was not until Willem Einthoven, of the University of Leyden, designed in 1903 (preliminary communication in 1901) his "string galvanometer", a far more sensitive and accurate instrument, that electrocardiography became a method of scientific value and practical medical importance.

As far as we are aware, it was also Einthoven who, in 1894, nine years before the main publication of his invention of the string galvanometer, introduced the term "electro-cardiogram" (Einthoven, 1894a) and "electrocardiogram" (without hyphen) (Einthoven, 1894b). Einthoven (1912) credited Waller with introducing this term into science, but we have been unable to trace any reference to the use of this term prior to Einthoven's papers of 1894.

In 1906 Einthoven recorded the electrocardiogram from electrodes placed on both arms and legs and, in 1908, termed the connections taken from the right arm and left arm Lead I; those from the right arm and left leg Lead II; and from the left arm and left leg Lead III. He also laid down in detail how the recording instrument should be built (described in 1909) and its sensitivity be standardised, so that tracings recorded by different investigators at different places could be compared. All subsequent workers have adhered to this standard until

more modern apparatus built on different principles were introduced about the middle of this century; see below in this chapter.

It was principally the pioneer work of Dr. T. Lewis, F.R.S. (afterwards Sir Thomas Lewis) in England, Professor H. B. Williams in the U.S.A., and Professors Wenckebach and Winterberg in Vienna, that greatly advanced the science of electrocardiography as a diagnostic method in the first thirty years of this century.

Einthoven's limb leads are still recorded whenever an electrocardiogram is taken, but from 1932 (Wolferth and Wood) leads taken from the chest wall have been added. It is of historical interest to note that in 1887 Waller had recorded chest leads in addition to limb leads but, apart from some exceptions in special studies (Lewis, 1909–12), the use of chest leads had subsequently been discarded under the influence of Einthoven's pioneer work, until they were re-introduced by Wolferth and Wood. In 1934, Wilson and his collaborators improved the technique of chest leads by making it possible to record the electrical changes of only the chest electrode, without any noticeable distortion of the tracing being caused by electrical changes of the second electrode; such leads are called unipolar chest leads (p. 23). The same idea was subsequently applied to limb leads, resulting in the augmented unipolar limb leads, introduced by Goldberger in 1942 (p. 24). For a more detailed description of the history and development of the electrocardiograph, see Barron (1950) and Goulding (1962).

Until about the middle of this century all electrocardiograms were recorded with Einthoven's string galvanometer. This is sufficiently sensitive to register the electrical currents of the heart accurately, but tracings were photographically recorded and had to be developed like any other photograph. From about 1950 onwards increasing use has been made of amplification techniques as applied to the design of wireless apparatus. This led to the construction of electrocardiographs in which the electrical currents of the heart were amplified by valves or, more recently, by transistors. Such amplification has made it possible to use far less sensitive, more robust, but equally accurate galvanometers, and to record tracings directly on specially prepared paper so that photographic development has become unnecessary. The same leads are recorded with these direct writing instruments as were formerly taken with the string galvanometer, so that the present technique is still fundamentally based on the principles put forward by Einthoven over half a century ago.

The first radical change from this principle has occurred with the introduction of the vectorcardiogram. Although rarely used in this country, a short description of it is given on pp. 120 *seq.*

Phonocardiography deals with the recording of sounds and murmurs produced by the heart.

The use of microphones and telephones for demonstrating heart

sounds goes back to 1878 (Ladendorf; Stein). The first graphic record of human heart sounds was published by Hürthle in 1893. He connected a microphone, placed on the chest, via an induction coil to a nerve-muscle preparation of a frog. The electrical currents generated by the heart sounds through the microphone caused twitches of the muscle which were recorded on a smoked drum. Hürthle recorded simultaneously the mechanical pulsations of the heart ("apexcardiogram") and used the heart sounds to analyse the apexcardiogram. Nowadays, more than half a century later, we have adopted the reverse procedure, using the apexcardiogram as one of several time-reference tracings to analyse heart sounds (see p. 111).

The first photographic records of heart sounds in rabbits and man were published by Einthoven and Geluk in 1894, that is, several years before Einthoven's invention of the string galvanometer. Einthoven used his string galvanometer for recording human heart sounds in 1907, and the earliest simultaneous heart-sound records with electrocardiograms were published by Kahn in 1909 and 1910, and Fahr (1912–13), both using one string galvanometer and superimposing the heart-sound currents on the ECG; Bull (1911) who projected a phonoscopic record on to the same camera as the ECG recorded by a string galvanometer; and Lewis (1912–13) using two string galvanometers with projections on to the same recording slit. For many years the recording of heart sounds attracted little attention, until advances in the design of microphones and the introduction of valve amplifiers greatly improved apparatus and techniques. The increased interest is reflected in the large number of publications on this subject during the last twenty years, and more recently this method has become increasingly important in the diagnosis of cardiac disorders (see Leatham, 1958).

REFERENCES

Barron, S. L. (1950). "The development of the electrocardiograph in Great Britain." *Brit. med. J.*, **1**, 720.

Bull, L. (1911). "On the simultaneous record of the phono- and electro-cardiogram." *Quart. J. exp. Physiol.*, **4**, 289.

Burdon-Sanderson, J., and Page, F. J. M. (1879–80). "On the time-relations of the excitatory process in the ventricle of the heart of the frog." *J. Physiol. (Lond.)*, **2**, 384.

Burdon-Sanderson, J., and Page, F. J. M. (1883–84). "On the electrical phenomena of the excitatory process in the heart of the frog and of the tortoise, as investigated photographically." *J. Physiol. (Lond.)*, **4**, 327.

Einthoven, W. (1894a). "Het meten van snel wisselende potentiaal verschillen met behulp van Lippmann's capillair-electrometer." *Onder. physiol. Lab. Leiden*, **2R, I**, 199. On p. 216.

Einthoven, W. (1894b). "Lippmann's Capillar-Electrometer zur Messung schnell wechselnder Potentialunterschiede." *Pflüg. Arch. ges. Physiol.*, **56**, 528. On p. 541.

Einthoven, W. (1901). "Un nouveau galvanomètre." *Arch. néerl. Sci. exactes nat.*, 2 sér., **6**, 625.

Einthoven, W. (1903). "Ein neues Galvanometer." *Ann. Phys. Lpz.*, **12**, 1059.

Einthoven, W. (1906). "Le télécardiogramme." *Arch. int. Physiol.*, **4**, 132.

Einthoven, W. (1907). "Die Registrirung der menschlichen Herztöne mittels des Saitengalvanometers." *Pflüg. Arch. ges. Physiol.*, **117,** 461.
Einthoven, W. (1908). "Weiteres über das Elektrokardiogramm." *Pflüg. Arch. ges. Physiol.*, **122,** 517.
Einthoven, W. (1909). "Die Konstruktion des Saitengalvanometers." *Pflüg. Arch. ges. Physiol.*, **130,** 287.
Einthoven, W. (1912). "The different forms of the human electrocardiogram and their signification." *Lancet*, **1,** 853. On p. 861.
Einthoven, W., and Geluk, M. A. J. (1894). "Die Registrirung der Herztöne." *Pflüg. Arch. ges. Physiol.*, **57,** 617.
Fahr, G. (1912–13). "On simultaneous records of the heart sounds and the electrocardiogram." *Heart*, **4,** 147.
Goldberger, E. (1942). "A simple, indifferent electrocardiographic electrode of zero potential and a technique of obtaining augmented, unipolar, extremity leads." *Amer. Heart J.*, **23,** 483.
Goulding, L. G. (1962). "Electrocardiography." *Instr. Practice*, **16,** 1229.
Hürthle, K. (1893). "Ueber die Erklärung des Cardiogramms mit Hülfe der Herztonmarkirung und über eine Methode zur mechanischen Registrirung der Töne." *Dtsch. med. Wschr.*, **19,** 77.
Kahn, R. H. (1909). "Weitere Beiträge zur Kenntnis des Elektrokardiogrammes." *Pflüg. Arch. ges. Physiol.*, **129,** 291.
Kahn, R. H. (1910). "Die Lage der Herztöne im Elektrokardiogramme." *Pflüg. Arch. ges. Physiol.*, **133,** 597.
Kölliker, A., and Müller, H. (1856). Nachweis der negativen Schwankung des Muskelstroms am natürlich sich contrahirenden Muskel." *Verh. phys. med. Ges. Würzb.*, **6,** 528.
Ladendorf, A. (1878). "Das Microphon als diagnostisches Hülfsmittel." *Berl. klin. Wschr.*, **15,** 565.
Leatham, A. (1958). "Auscultation of the heart." *Lancet*, **2,** 703, 757.
Lewis, T. (1909–12). "Auricular fibrillation and its relationship to clinical irregularity of the heart." *Heart*, **1,** 306.
Lewis, T. (1912–13). "Illustrations of heart-sound records." *Quart. J. Med.*, **6,** 441.
Matteucci, C. (1843). "Sur le courant électrique des muscles des animaux vivants ou récemment tués." *C.R. Acad. Sci. (Paris)*, **16,** 197.
Stein, S. T. (1878). "Das Sphygmophon, ein neuer electro-telephonischer Apparat zur Diagnose der Herz- und Pulsbewegungen." *Berl. klin. Wschr.*, **15,** 723.
Waller, A. D. (1887). "A demonstration on man of electromotive changes accompanying the heart's beat." *J. Physiol. (Lond.)*, **8,** 229.
Wilson, F. N., Johnston, F. D., Macleod, A. G., and Barker, P. S. (1934). "Electrocardiograms that represent the potential variations of a single electrode." *Amer. Heart J.*, **9,** 447.
Wolferth, C. C., and Wood, F. C. (1932). "The electrocardiographic diagnosis of coronary occlusion by the use of chest leads." *Amer. J. med. Sci.*, **183,** 30.

CHAPTER 3

BIOLOGICAL ASPECTS

FROM the biological point of view the technician requires an understanding of the following aspects:

The nature of an electrocardiogram, the features of a normal record, and the factors influencing it.

THE NATURE OF AN ELECTROCARDIOGRAM

What exactly is recorded when an electrocardiogram is taken?

An electrocardiogram is a graphic record of the electrical currents produced by the heart during its action. Every contraction of the heart, just as the activity of any other excitable living tissue, is associated with changes in electrical potential and it is the effect of these which is recorded as an electrocardiogram.

These changes can best be understood by first considering the electrical behaviour of a single cell. The fundamental observation is that the surface of a *resting* cell is electrically positive compared with the interior of the cell. The term electrically positive means that it behaves like the copper electrode of a battery in relation to its zinc electrode. As the exterior and interior of the cell can thus be compared with the two poles of a battery, a cell in this condition is also said to be "polarised". When the cell is in the *excited* state—owing to being stimulated; for example, mechanically, or electrically, or by a stimulus applied to the cell by a nerve—the difference in the electrical state between the negative interior and the positive exterior of the cell is temporarily abolished; the excited cell can no longer be compared with the poles of a battery and is, therefore, said to be "depolarised". When the effect of excitation has passed off and the cell has returned to its former resting state, the positive charge outside and the negative charge inside the cell are restored, the cell being "repolarised". (This simplified description disregards the result of more recent investigations showing that the electrical changes during excitation are more complicated; though these findings are irrelevant in the present context, a brief description is given in an appendix to this chapter.)

If a resting uninjured strip of muscle is next considered (Fig. 3.1 (A)), consisting of a great number of resting cells, no differences in electrical potential exist on its surface, since all the cells are in the same electrical, namely polarised, condition. Therefore, if one wire is placed on the

end X, a second wire on the end Y, and these wires are connected through a galvanometer G, no electrical current will flow through these wires of the external circuit and the galvanometer will not show any deflection. If one end of the strip is then stimulated (for example, the end X, as indicated by the arrow St in Fig. 3.1 (B)), the cells on the stimulated portion become depolarised. As their surface is no longer electrically positive (actually, it becomes temporarily negative), whereas the surface of the cells of the resting portion at Y is still positive, the latter is electrically positive in relation to the stimulated part. An electrical current will, therefore, flow from the resting to the stimulated portion, causing the needle of the galvanometer G to deflect. In Fig. 3.1 (B) this is illustrated by the arrows showing the direction of current in the external circuit to be from Y to X. The direction of the deflection depends on the direction, and its magnitude on the strength, of the current. From the electrical point of view, the spread of the excitation through the muscle strip can be compared to the movement of a wave of electrical potential with its positive pole in front (indicated in Fig. 3.1 (B) by the + and − signs at the boundary between the stimulated and resting portions of the strip). "In other words, we may say that, across the boundary between active and resting muscle, there is an electromotive force which makes the potential of points toward which the excitation wave is advancing positive, and the potential of points which lie behind it negative" (Wilson and collaborators, 1944). When subsequently the excitation has activated the whole strip, all the cells are in the excited, that is, depolarised state. Consequently, there is no difference in electrical potential between any points of the surface of the strip, no current will, therefore, flow through the external circuit and the galvanometer needle will return to its zero position (Fig. 3.1 (C)). When the effect of stimulation has subsided, the strip returns to its resting state, recovery starting at the point X which was previously stimulated. At this moment the cells of the recovered portion are again in the polarised state and their surface is electrically positive in relation to the surface of the still excited (depolarised) cells. The differences in electrical potential at this stage are, therefore, of the opposite direction from those during the spread of excitation. In the external circuit, current will therefore flow from the already recovered to the still excited portion of the muscle strip. This is indicated in Fig. 3.1 (D) by the arrows showing the direction of current in this circuit to be from X to Y, and the direction of deflection of the galvanometer G to be in the opposite direction from that in Fig. 3.1 (B). If the strip be again compared to a battery, it behaves as if its poles were now reversed. When subsequently the whole strip has recovered, all the cells are again in their resting (polarised) state. The electrical potential at all points on the strip being the same, no current will flow in the external circuit and the galvanometer needle will return to zero

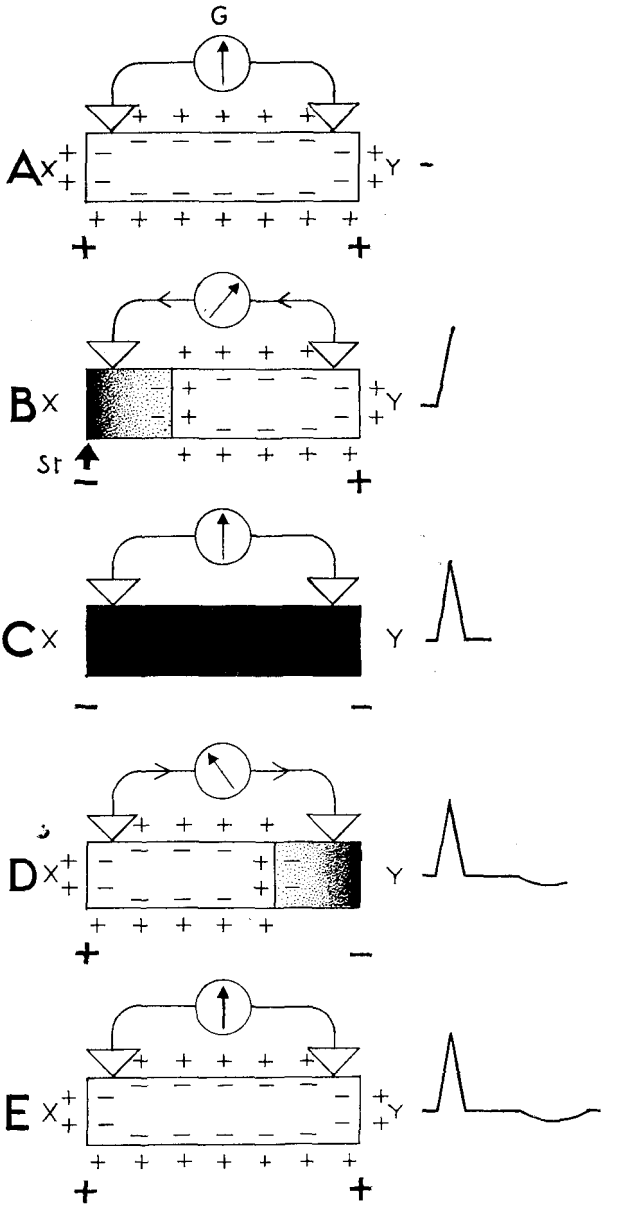


FIG. 3.1. Diagrams illustrating the electrical changes associated with the spread and recession of excitation through an uninjured strip of muscle. The strip is indicated by a rectangle, from the two ends of which, marked X and Y, the potentials are led off to a galvanometer G. White: resting (polarised) muscle; black: excited (depolarised) muscle; stippled: boundary zone. The record of the galvanometer deflections in the course of excitation and recovery of the strip are indicated on the right. For further explanation, see text.

(Fig. 3.1 (E)). It will be seen that the excitation and subsequent recovery of the muscle strip have given rise to two electrical currents of opposite directions. This is called a diphasic action current. The currents of repolarisation (during recovery) are weaker and extend over a longer period of time than those of depolarisation (during excitation). In the diagrammatic illustration of the record of an action current on the right of Fig. 3.1 this is shown by the higher deflection of shorter duration during excitation, compared with the shallow deflection of longer duration during recovery.

Applying this to the electrical changes produced by the heart beat, the same fundamental principle holds, though with important modifications. Instead of being a simple muscle strip, the musculature of the heart consists of a great multitude of intercommunicating muscle fibres. Also, the heart consists of four chambers which are activated by the excitation in a sequence far more complicated than the simple spread of the excitation through a muscle strip. Lastly, while in experiments on animals it is possible to connect the heart muscle itself by wires to a galvanometer, in recording such currents in man use is made of the fact that the electrical currents spread throughout the human body, thus making it possible to record them from the surface of the body. The changes in electrical potential, as recorded in human electrocardiography, are therefore led off, not from the heart direct, but from the surrounding medium. This profoundly modifies the currents as eventually recorded, both quantitatively and qualitatively. Most authorities accept the view that the body behaves like a volume conductor, that is to say, that the heart is a source of electromotive forces in a large conducting medium. The various tissues of the body interposed between the heart and the recording electrodes act to different degrees as resistors and short-circuits, but opinions vary as to how much this affects the electrocardiogram.

While the mode of origin of the electrocardiogram is discussed below, one point may be anticipated in connection with the above description of the diphasic action current. If the order, in which the recovery (or repolarisation) of the different portions of the heart takes place, were the same as that of the preceding excitation (or depolarisation), the action currents of one heart beat would be diphasic. The portion inscribed in the record during recovery would be of opposite direction from that recorded during excitation. But this is not the case: the order in which the several portions of the heart recover differs from that in which they had previously been excited. The sequence is such that, in the normal heart, the electrical currents during recovery produce, on the whole, deflections of the same direction in the electrocardiogram as those occurring during excitation. The currents due to recovery take longer and are weaker than those due to excitation, as already mentioned in the description of the diphasic action current.

THE FEATURES OF A NORMAL RECORD AND THE FACTORS INFLUENCING IT

One relevant aspect of the mode of origin of the electrical changes, as they affect the magnitude and direction of the deflections of the recording galvanometer, follows from Wilson's comparison, quoted above, of such electrical changes with a moving wave of electrical potential: the galvanometer deflection depends, amongst other factors (e.g. velocity of the spread of excitation), on the direction of the spread of the excitation which gives rise to the electrical changes. Applying this to the electrocardiogram, it follows that this record is decisively influenced by the direction of the spread of the excitation wave in the heart in relation to the points from which the electrocardiogram is recorded, that is, the points at which the recording electrodes are placed on the subject's body. This relationship, in turn, depends on the following factors:

(1) The direction in which the excitation wave spreads and recedes through the heart, or in other words, the sequence in which the different parts of the heart are excited (depolarised), and in which they subsequently recover (are repolarised);

(2) The points on the body chosen for applying the electrodes which lead off the heart's electrical changes to the recording galvanometer ("Lead");

(3) The position of the heart in relation to the rest of the body, and thereby to the position of the electrodes; this varies in different subjects; and

(4) The physiological or pathological changes in the heart affecting the origin and/or spread of the excitation wave. This constitutes, of course, the basis of the diagnostic value of this method. Its understanding necessitates medical training and this aspect is outside the technician's scope.

The first three factors will now be discussed in the above order.

1. The Direction of Spread and Recession of the Excitation in the Heart

The impulse, which stimulates the heart to contract and gives rise to the electrical changes recorded as an electrocardiogram, originates in a small circumscribed part of the heart and spreads through a special conducting system through, and to the various portions of, the heart. Knowledge of the anatomical position of the focus of origin of the normal impulse and of that of the conducting pathways is essential for understanding the features of the electrocardiogram. It is, therefore, opportune briefly to recall some elementary data of the anatomical structure and the function of the human heart, followed by a description

of the location within the heart of the site of origin and the pathways of conduction of the excitation wave.

Anatomical and Physiological Data

The human heart lies in the chest between the two lungs, behind the lower two-thirds of the breast bone, in front of the œsophagus and above the diaphragm on which it rests (Fig. 3.2). Roughly conical in shape, its base is directed upwards, to the right and backwards, its apex downwards, to the left and forward. About two-thirds of the organ

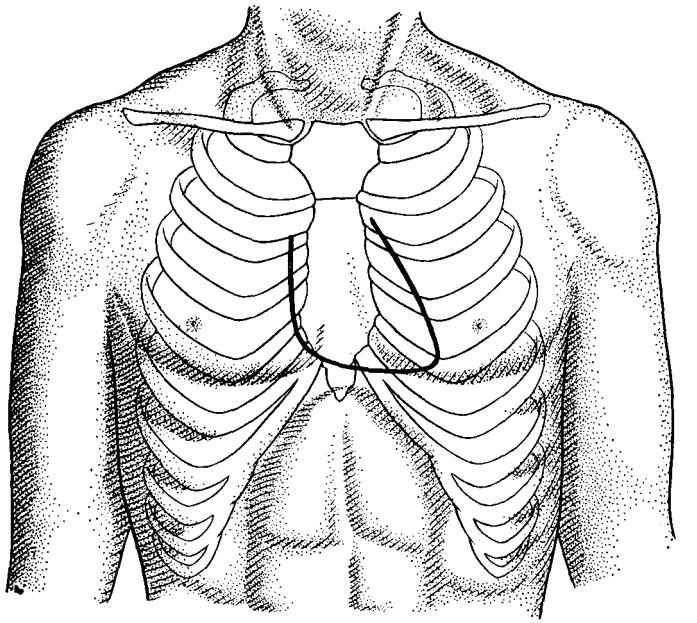


FIG. 3.2. Outline of heart indicating its position in the chest. It varies considerably in different subjects.

lies to the left and one-third to the right of the midline. Its size corresponds approximately to that of its owner's clenched fist. It consists of four chambers: right and left atrium, and right and left ventricle. The right ventricle and atrium lie in front, the left ventricle and atrium behind, the left ventricle also forming the left border and the apex of the heart. Both atria have an extension called the auricular appendages. The atria are separated from one another by the atrial septum, the ventricles by the ventricular septum. The left atrium communicates with the left ventricle by the left atrio-ventricular, or mitral orifice, the right atrium with the right ventricle by the right atrio-ventricular, or tricuspid orifice. See Fig. 3.3.

Fig. 3.4 provides a diagrammatic illustration of the circulation. From the various parts of the body venous blood returns to the right atrium via the great veins (superior and inferior venæ cavæ) and the coronary sinus (see below), reaching the right ventricle through the tricuspid orifice. The right ventricle propels it into the pulmonary

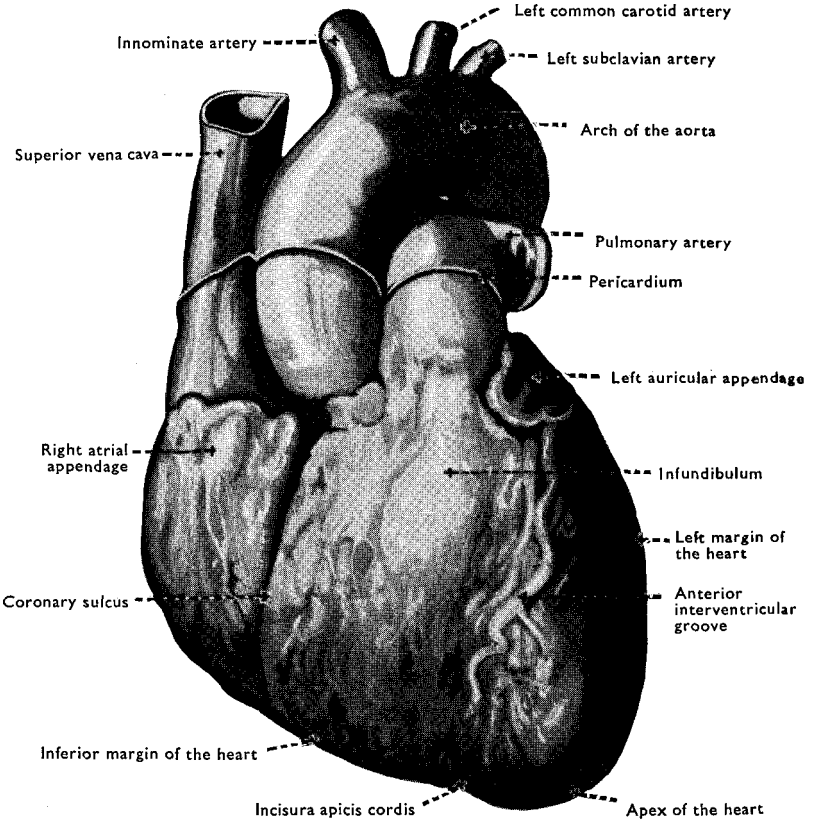


FIG. 3.3. (*a*) Heart, anterior surface.
From Kiss and Szentágothai, *Atlas of Human Anatomy.*

artery, through the branches of which it reaches the lungs, there to take up oxygen and give off carbon dioxide. The blood thus oxygenated returns to the left atrium by the four pulmonary veins. All this part of the circulatory system is called pulmonary, or lesser, circulation. From the left atrium the blood passes into the left ventricle through the mitral orifice and is ejected by the left ventricle into the aorta, its branches carrying it into the various parts of the body, this portion of

the circulation being termed systemic circulation. Four valves ensure that the blood flows in one direction only: the right atrio-ventricular, or tricuspid valve, guarding the right atrio-ventricular opening and having three cusps, prevents the backflow of blood from the right ventricle into the right atrium during contraction of the right ventricle; the pulmonary valve, at the origin of the pulmonary artery from the

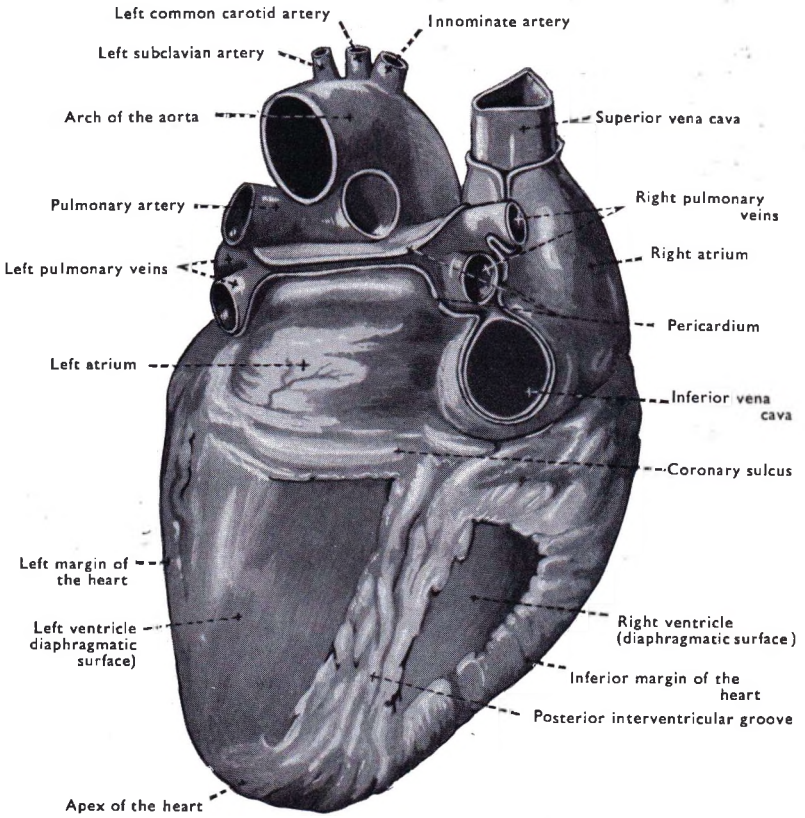


FIG. 3.3. (*b*) Heart, postero-inferior surface.
From Kiss and Szentágothai, *Atlas of Human Anatomy*

right ventricle, prevents the backflow of blood from the pulmonary artery into the right ventricle during relaxation of the right ventricle; the left atrio-ventricular, or mitral valve, guarding the left atrio-ventricular opening, and having two cusps, prevents the backflow of blood from the left ventricle into the left atrium during contraction of the left ventricle; and the aortic valve, at the root of the aorta, that is,

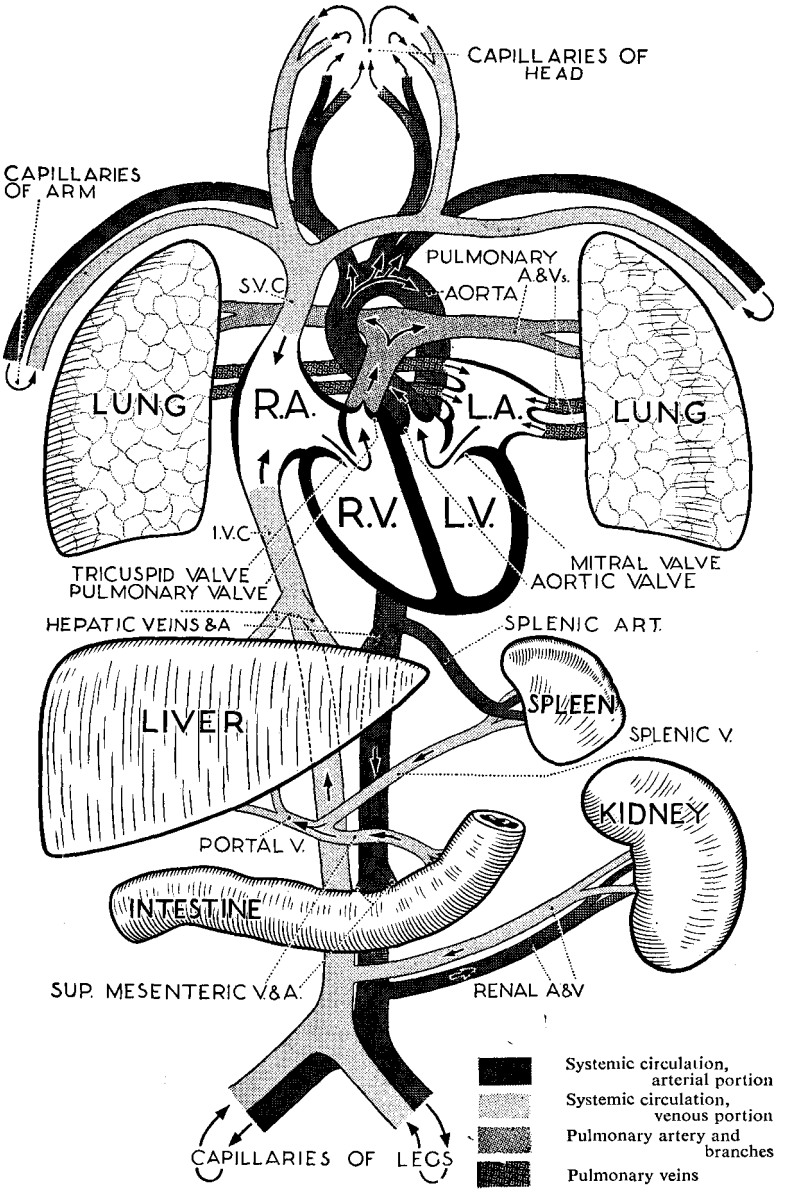


FIG. 3.4. Diagram of the circulation of the blood. R.V.: Right ventricle. L.V.: Left ventricle. R.A.: Right atrium. L.A.: Left atrium. S.V.C. Superior vena cava. I.V.C.: Inferior vena cava. A.: Artery. V.: Vein.

its origin from the left ventricle, prevents the backflow of blood from the aorta into the left ventricle during relaxation of the left ventricle.

The heart derives its blood supply from the two coronary arteries, which originate from the first part of the aorta. The venous blood of the heart returns to the right atrium via the coronary veins and the coronary sinus which opens into the right atrium near the tricuspid valve.

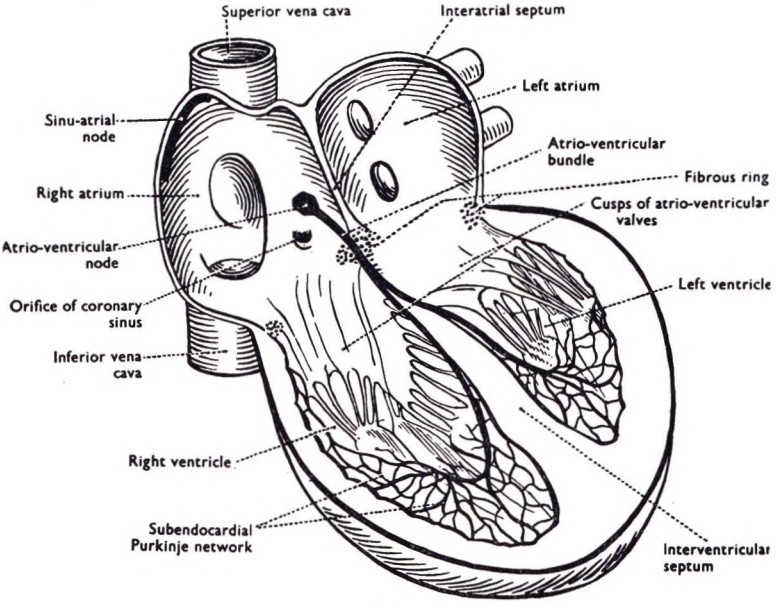
The activity of the heart is rhythmical, consisting of alternate phases of contraction, or systole, and relaxation, or diastole. The two atria contract nearly simultaneously, and so do the two ventricles, but the contraction of the atria precedes that of the ventricles by about 0·16 second. The delay of the contraction of the ventricles relative to that of the atria makes it possible for the atria to fill the relaxed ventricles with blood before the latter contract. This order of activation of the several chambers of the heart is due to the way in which they are activated by the wave of excitation, which will now be described.

The Specialised Conducting System. Anatomy

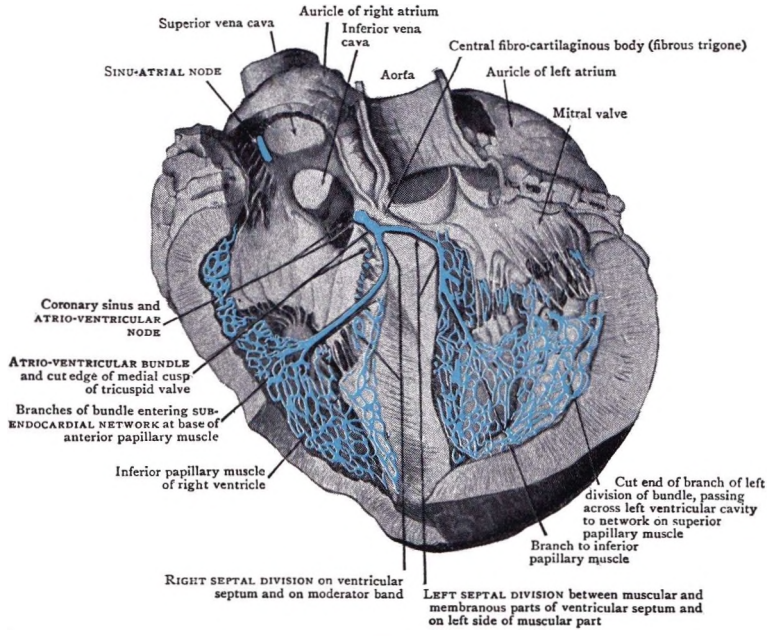
By this term a system of specialised tissue is understood in which the stimulus of cardiac excitation originates and is conducted. Some of it can be demonstrated to the naked eye, and most of it can be differentiated microscopically from the common muscle of the heart which by its contraction propels the blood. The specialised system can conveniently be divided into two main parts: the sinu-atrial node and the atrio-ventricular system (see Fig. 3.5).

The sinu-atrial (S–A) node begins with a broad upper segment, termed the head, in the angle between the superior vena cava and the right atrium. Its lower portion, called its tail, extends to the orifice of the inferior vena cava in the right atrium near its junction with the right ventricle. The S–A node is about 2 cm long and 2 mm wide. It is the head of the sinu-atrial node which is normally the site of origin of the cardiac impulse and this structure is, therefore, also called the normal pacemaker.

The atrio-ventricular (A–V) system begins with the atrio-ventricular node, which lies in the right atrium above the orifice of the coronary sinus. It is about 5 mm long and 2–3 mm wide. Toward the ventricles the arrangement of the cells composing the specific tissue gradually becomes more parallel, forming what is known as the bundle of His (who first described it in 1893); this runs from the A–V node to that upper and posterior portion of the ventricular septum which is devoid of muscle fibres and, being therefore transparent when held against the light, is called the membranous part of the ventricular septum. Just below it the bundle of His divides into two main branches, the right and left bundle branch, supplying the right and left ventricle respectively (see Fig. 3.5). Both these branches then subdivide into smaller and smaller branches, called Purkinje fibres. These eventually form a net-



(*a*)


Auricle of right atrium
Superior vena cava
Inferior vena cava
Central fibro-cartilaginous body (fibrous trigone)
SINU-ATRIAL NODE
Aorfa
Auricle of left atrium
Mitral valve
Coronary sinus and ATRIO-VENTRICULAR NODE
ATRIO-VENTRICULAR BUNDLE and cut edge of medial cusp of tricuspid valve
Branches of bundle entering SUB-ENDOCARDIAL NETWORK at base of anterior papillary muscle
Inferior papillary muscle of right ventricle
Cut end of branch of left division of bundle, passing across left ventricular cavity to network on superior papillary muscle
Branch to inferior papillary muscle
RIGHT SEPTAL DIVISION on ventricular septum and on moderator band
LEFT SEPTAL DIVISION between muscular and membranous parts of ventricular septum and on left side of muscular part

(*b*)

FIG. 3.5. The specific conducting system. (*a*) Diagrammatic. From Mitchell and Patterson, *Basic Anatomy*. (*b*) From Cunningham, *Textbook of Anatomy*.

work of fibres, visible only microscopically, which invest the inside of the ventricles and transmit the excitation to the common muscle of the ventricles. There are certain differences between the right and left bundle branch, before their sub-division, the most important being: the left one pierces the septum and divides soon after its origin from the main bundle of His, one of its branches supplying the septum itself; the right bundle branch, on the other hand, runs as an undivided small cord for a longer distance before sub-dividing.

The Specialised Conducting System. Physiological Function

As already stated, the normal site of impulse formation of the heart is the head of the sinu-atrial node. From there the excitation wave spreads radially in all directions through the two atria; no specific conducting pathways in the atria are known as those described in the ventricles. After spreading in this way through, and activating the atria, the excitation wave reaches the A–V node where some delay in its further transmission occurs. It is this delay which chiefly accounts for the fact that the ventricles contract on an average 0·16 second after the atria. From this node the excitation wave passes through the bundle of His, its two main branches and their ramifications, the Purkinje fibres, to conduct the impulse to the common muscle of the ventricles. This anatomical arrangement and the high rate of conduction of the impulse through the network of Purkinje fibres, namely, about 4 metres per second, result in the whole of both ventricles being activated by the impulse in less than 0·1 second.

The Component Parts of the Normal Electrocardiogram and their Physiological Significance

The location of the site of impulse formation and the mode of spread of the excitation wave, as described, account for the features of the electrocardiogram as recorded in clinical work.

The formation of the cardiac impulse in the sinu-atrial node is not recorded in the electrocardiogram. Its first deflection is produced by the activation of the atria and is called the atrial wave, or P wave (see Fig. 3.6). Recorded by the usual technique, its height as a rule does not exceed 2·5 mm and its duration varies between 0·07 and 0·11 second, values of 0·07–0·09 second being found in children. For normal variations of this and the other deflections in the electrocardiogram, see Table I, pp. 37 and 38.

After the activation of the atria the excitation wave spreads through the A–V node, the stem of the bundle of His, its two main branches and its ramifications, the Purkinje fibres. No deflections are recorded in the electrocardiogram during this interval; the next event, recorded in the tracing, is the activation of the ventricles. For this reason there is.

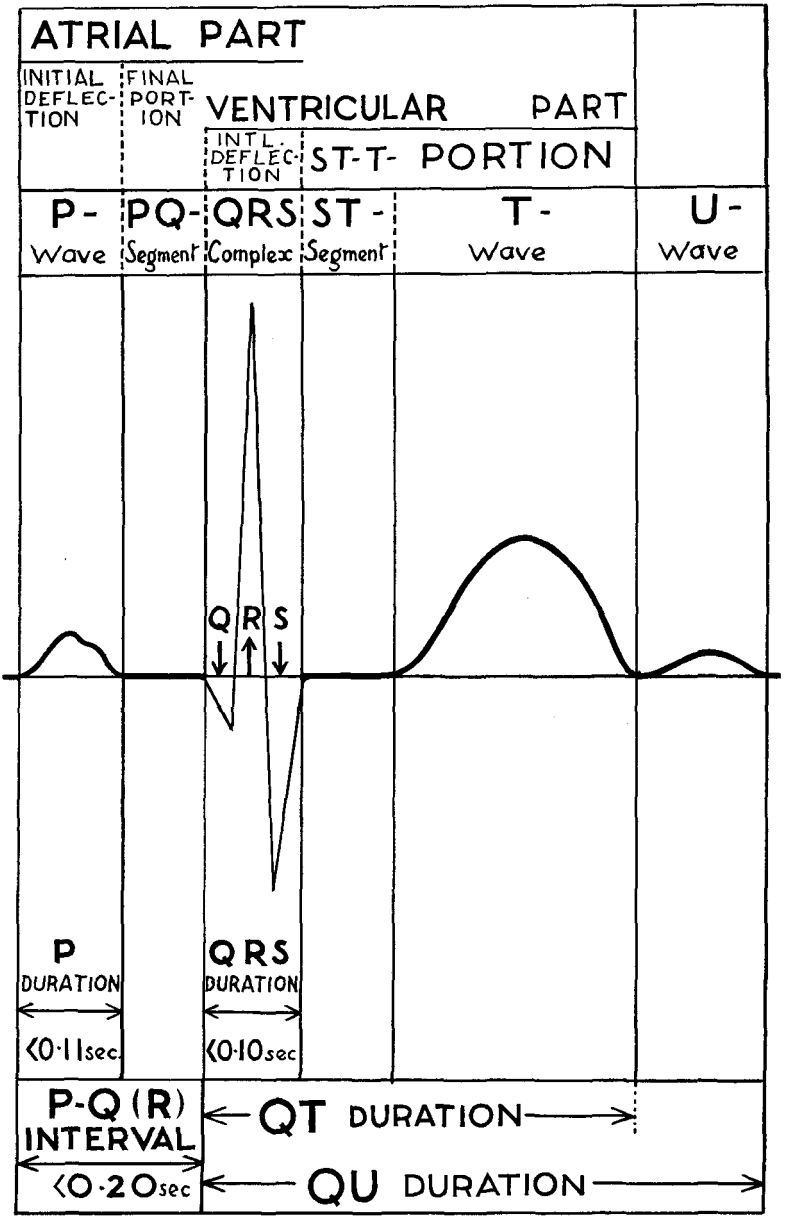


FIG. 3.6. Diagram of one cycle of a normal electrocardiogram. Adapted from Holzmann, *Klinische Elektrokardiographie.*

between the activation of the atria, manifested by the P wave, and that of the ventricles, manifested by the QRS complex (to be described), an interval of electrical quiescence. During this, the record shows a straight line in or just below its zero position, also called the iso-electric line. This interval includes the delay of the excitation during the passage through the A–V node, mentioned above.

As soon as the excitation has reached the common muscle of the ventricles the ventricular electrocardiogram begins to be inscribed. This consists of two parts: the QRS complex, or initial ventricular deflection, due to ventricular excitation (or depolarisation), and the T wave, or terminal deflection, being the electrical manifestation of ventricular recovery (or repolarisation).

The QRS complex consists normally of a short Q wave, directed downward, measuring up to 4 mm, with a duration of 0·02 second. This is followed by a much higher upright deflection, the R wave, which varies in height and may normally measure up to 29 mm. The R wave is, in turn, followed by another small wave, directed downward, the S wave, varying in depth up to 29 mm. These figures are maxima; for normal ranges see Table I, pp. 37 and 38. Either the Q wave or the S wave may be absent. The duration of the QRS complex, measured from the beginning of the Q (or, in the absence of a Q, of the R) wave to the end of the S (or, in the absence of an S, of the R) wave varies in normal hearts between 0·05 and 0·10 second, the lower values being found in children. The duration of this initial ventricular deflection indicates the time required for the excitation of the ventricles. When this is completed the tracing returns to, or very close to, its zero position, since at that moment no significant differences of potential exist in the heart. But almost immediately after this stage is reached, repolarisation of ventricular musculature begins, which is associated with changes in electrical potential in the heart, giving rise to the T wave. The T wave forms one part of the final deflection which also includes the S–T segment (in the absence of an S wave, the R–T segment). The S–T segment is the portion of the record between the end of the QRS complex and the beginning of the T wave. It begins at its junction with the end of the S (R) wave, also called the S–T (R–T) junction.

The S–T junction is normally on the baseline but may lie up to 1 mm above or below it. The S–T segment also lies on the baseline or slightly (up to $\frac{1}{2}$ mm) above or below it. In some instances the beginning of the T wave, that is its ascending limb, begins immediately after the end of the QRS complex so that an S–T segment is absent. The normal T wave has a slow ascending limb and a steeper and shorter descending one so that it is asymmetrical. It varies in shape, being sometimes round, at other times peaked, and also in height and direction in the various records (leads, see below) of the same subject. It is usually much lower than the R wave.

In some, but by no means all records, a low and slow deflection is recorded after the T wave: the U wave. It is found either in the descending limb of the T wave, or as a separate wave immediately after it. Its mode of origin is complex and in some respects still controversial.

Each of these waves which compose the normal electrocardiogram has certain variations in height, shape and duration in different individuals. The same holds good for the various leads of the same individual.

2. The Leads of the Electrocardiogram

It has been pointed out above that, in electrocardiography, the deflections of the recording galvanometer depend, amongst other factors, on the direction of the spread of the excitation wave through the heart relative to the points from which the electrical currents are led off from the subject's body. In order to be able to compare records taken by different observers it is therefore necessary to record such tracings from definite and agreed points of the body. Furthermore, since an electrocardiogram is a record of the electrical currents which the subject's heart generates, the subject's body must be connected to the galvanometer in such a way that there is a closed circuit; that is to say, one wire leading the current from the body to the galvanometer, and a second wire returning it from the galvanometer to the body. Such a circuit is called a Lead. The Leads commonly used are as follows:

Right arm—left arm, called Lead I, also written 1.
Right arm—left leg, called Lead II, also written 2.
Left arm—left leg, called Lead III, also written 3.

As mentioned in the historical chapter, these three leads were originally introduced by Einthoven, the founder of clinical electrocardiography. They are also termed the standard, or bipolar, limb leads.

In addition to these limb leads, chest leads (also termed precordial leads) are now universally taken, in which one of the recording electrodes is placed on the chest wall near the heart. Owing to the proximity to the heart of such a chest electrode, the changes in electrical potential beneath it are larger than those beneath a limb electrode, that is to say, in excess of those recorded by another electrode, put at a distance from the heart, with which it is paired. Also, a slight variation in the placing of the chest electrode will result in far more pronounced changes in the recorded tracing than a slight change in placement of the distant electrode. For this reason the chest electrode is also called the exploring electrode and distinguished from the distant one, which is also termed indifferent electrode. The potentials recorded from the

exploring electrode are characteristic for a small area on the chest wall and very largely determined by the subjacent portion of the heart. It is, therefore, possible to explore considerable parts of the right and left ventricles over the precordial area, provided that the electrode is sufficiently small; otherwise potentials of too large an area are recorded. For this reason the exploring chest electrodes are only about 2 cm in diameter, compared with 5×4 cm of the electrodes applied to the limbs

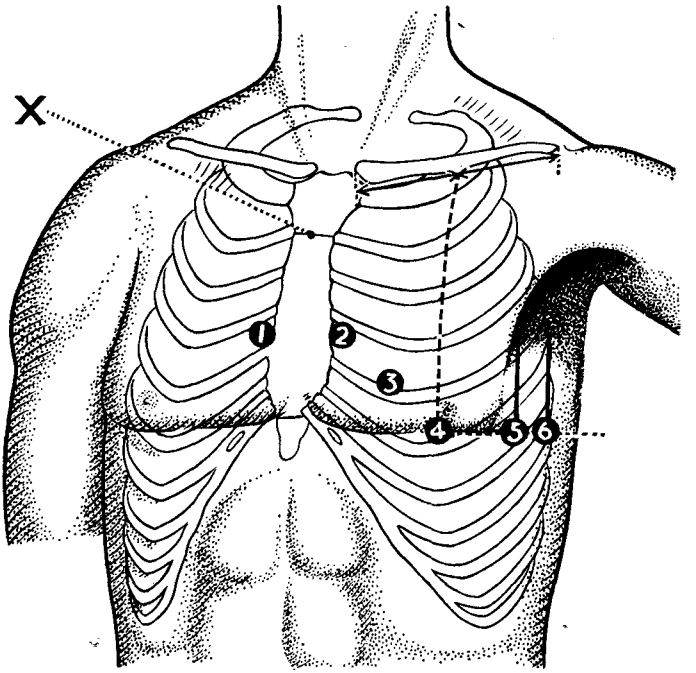


FIG. 3.7. Location on the chest wall of the six points from which the customary chest leads are taken. X.: Sternal angle. Broken line: Left midclavicular line.

(where the size of the area covered by the electrode does not matter materially).

Since, as already referred to, a slight change in the location on the chest wall of the exploring electrode results in conspicuous changes of the electrocardiogram, it is essential that precordial records are taken from well defined agreed points on the chest wall, otherwise no comparison between different tracings would be possible. These points, chosen in accordance with the recommendations of the British Cardiac Society and the American Heart Association, are (see Fig. 3.7):

Point 1: junction of the 4th intercostal space and the right sternal border;
Point 2: junction of the 4th intercostal space and the left sternal border;
Point 3: midway between points 2 and 4;
Point 4: the 5th intercostal space at its intersection with the left midclavicular line;
Point 5: in the left anterior axillary line horizontally from point 4;
Point 6: in the left midaxillary line at the same horizontal level as points 4 and 5.

The intercostal spaces are conveniently determined from the second intercostal space which is easily ascertained by its position immediately below the sternal angle.

These points refer to the position of the exploring electrode. The other, indifferent electrode, with which it is paired, used to be placed either on the right arm, or the left arm, or the left leg. These placements are designated by the letters R, L, and F (for foot), respectively.*

In practice, the indifferent electrode is now hardly ever placed on the left arm or leg, and in only a few hospitals on the right arm. The vast majority of chest leads are at present taken with an indifferent electrode specially designed to minimise its effect on the record from the exploring chest electrode. The reason for such a special indifferent electrode and the idea underlying its construction are as follows:

If the exploring chest electrode is paired with an indifferent electrode placed, for example, on the right arm, the indifferent electrode influences the record to a much smaller extent than the exploring one, as already referred to. But the electrical changes which take place beneath the indifferent electrode are not wholly negligible in such a chest lead and in some cases exert a still noticeable effect on the tracing. Attempts were therefore made to pair the exploring electrode with one whose variations of potential during cardiac activity were as nearly zero as possible.

Such a far more "indifferent" electrode was designed by Wilson and co-workers (1934) by joining each of the wires of the right arm, left arm and left leg electrodes through resistances of 5,000 ohms to one central terminal (Fig. 3.8). In this design, use is made of the fact that the algebraic sum of the potentials simultaneously present in the right arm, left arm and left leg equals zero. If the exploring electrode is paired

* In order to describe such a chest lead, the letter C is used, followed by the letter indicating the position of the indifferent electrode, followed in turn by the numeral of the point of application of the exploring (chest) electrode. Thus, a chest lead recorded with the indifferent electrode on the right arm, and the exploring electrode at the 4th intercostal space at the left sternal border would be designated CR–2. Similarly, lead CF–5 indicates a record taken with the indifferent electrode on the left leg and the exploring one in the left anterior axillary line at the same horizontal level as point 4 (which is in the 5th intercostal space in the midclavicular line).

with such a central terminal, the galvanometer records almost exclusively the changes in potential beneath the exploring electrode: that is, of one pole of the circuit as it is led off from the subject's body, and is therefore called a unipolar lead. It is designated by the letter V (for

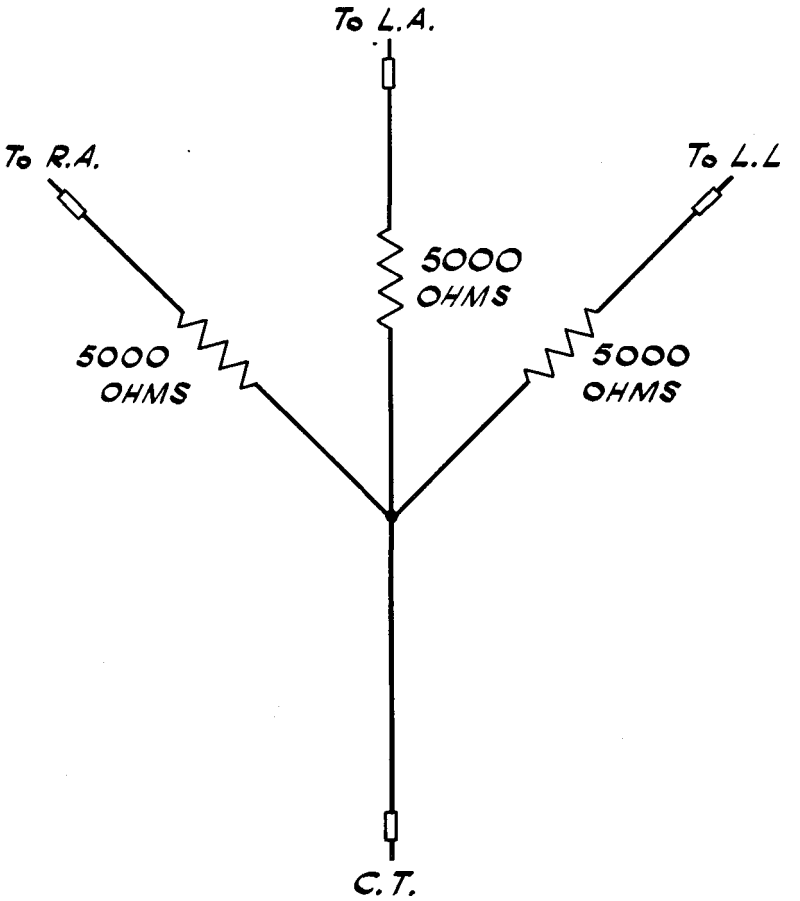


FIG. 3.8. Diagram of Wilson's Central Terminal. The resistances of 5,000 ohms are incorporated for the purpose of counteracting differences of skin electrode resistance beneath the three limb electrodes. In some modern cardiographs the resistances are higher, up to 100,000 ohms in each branch.

voltage), followed by the numeral indicating the position of the exploring electrode. For example, V4 indicates a lead in which the exploring electrode was placed in the 5th intercostal space at its intersection with the left midclavicular line and paired with Wilson's central terminal.

More recently, since 1942, the same principle of unipolar leads has

also been applied to leads recorded from the two arms and left leg. Regarding such limb leads, the three standard leads, as described above, are "bipolar" ones, because the recorded electrical effect is the resultant of the electrical changes occurring beneath both electrodes. For instance, in lead 1, obtained from the right arm and left arm, the recorded electrical changes are due to the difference between those of the left and the right arm. The individual electrical changes beneath each of the two electrodes are not recorded separately. As the scope of electrocardiography widened it became desirable to supplement the bipolar (standard) limb leads by those which record the electrical potentials beneath each individual limb electrode, that is, the variations in potential in the right arm, those in the left arm, and those in the left leg. In other words, to record unipolar limb leads in which the exploring electrode is paired with one whose changes in potential during cardiac activity are as near zero as possible. This can be done in a way similar to that practised with chest leads, as described above, that is, pairing the "exploring" limb electrode with a central terminal constructed after Wilson. (The unipolar left leg lead recorded by this method (termed lead VF) is employed by some investigators in connection with vectorcardiography (see p. 123).) But in recording unipolar *limb* leads the method most commonly used is the one recommended by Goldberger (1942), in which the electrode of the limb, the potentials of which are to be recorded, is paired with a common terminal constructed (without incorporated resistances) by joining the terminals of the two other limb electrodes. For example, if it is desired to record the unipolar lead of the right arm, the right arm electrode is paired with a terminal joining the leads from the left arm and left leg; in order to record the unipolar left arm lead, its terminal is paired with a terminal joining the right arm and left leg leads. The mathematical analysis shows that, in records obtained by this technique, deflections are recorded which are 50 per cent increased above the actual potentials present in the explored limb. For this reason they are called "augmented unipolar limb leads", designated by the letter a (for augmented), followed by the letter V (for voltage), indicating in this way that the record is a unipolar one, just as in the case of unipolar chest leads, followed in turn by the letter R, L or F, according to whether the lead was recorded from the right arm: aVR (also written aVr), left arm: aVL (aV1), or left leg: aVF (aVf).

This augmentation is an advantage since the potentials are rather small. In practice, the connections necessary for recording unipolar chest and augmented unipolar limb leads are incorporated in a switch of the electrocardiograph.

The twelve leads discussed so far are those usually recorded in a routine electrocardiogram. They are the three standard bipolar limb leads, the three augmented unipolar limb leads, and the six chest leads

recorded from the agreed points on the chest wall. They comprise, therefore, leads I, II, III, aVr, aVl, aVf, V–1, V–2, V–3, V–4, V–5, V–6, see Fig. 3.9.

In special cases additional chest leads are taken, for example, in patients in which the above twelve leads do not make it possible to arrive at a diagnosis with certainty. These are sometimes recorded with the exploring chest electrode in the left posterior axillary line, at the same level as points 4–6, this point being designated by the numeral 7, or at the same level from the back in the scapular line (angle of scapula) (point 8). At times the exploring electrode is placed 1 and/or 2 intercostal spaces higher than the conventional location, at other times chest leads are recorded from points on the right chest corresponding to the described points on the left side, in which case the letter R is added to their designation, for instance V4R (sometimes written R4 for short). Occasionally the exploring electrode is placed over the lowest portion of the breastbone, called the ensiform process, a unipolar lead thus recorded being designated VE; or it may be introduced into the œsophagus, the resulting œsophageal lead recording mainly the potentials of certain portions of the posterior aspect of the heart. More recently, by means of a special catheter the exploring electrode has also been introduced into the cavities of the heart, thus recording intracavitary leads.

In all unipolar leads the connections are made in such a way that positivity beneath the exploring electrode produces an upward deflection in the record.

Einthoven's Triangle and Law

From the technician's point of view the differences in height of the several waves in the three standard limb leads, in particular of the main waves of the initial ventricular deflections (R and S waves) are of special importance. The heights of these waves are interrelated in a simple way which can be summarised by the equation: Lead II = Lead I + Lead III. This relationship was first stated by Einthoven in 1908, its mathematical proof given by Einthoven and his co-workers in 1913, and is known as Einthoven's law. The underlying principle is as follows:

In a simplified manner, the heart may be considered as a source of an electromotive force which is situated in the centre of an equilateral triangle. The corners of the triangle are the right and left shoulders and left groin, that is, the points of attachment to the trunk of the three limbs whose potentials are recorded. (From the electrical point of view, the arms and leg can be regarded as wires which transmit the electrical changes passively without affecting the record.) All the potential differences created by the heart at any given moment can be represented by *one* potential difference, which can be constructed from all

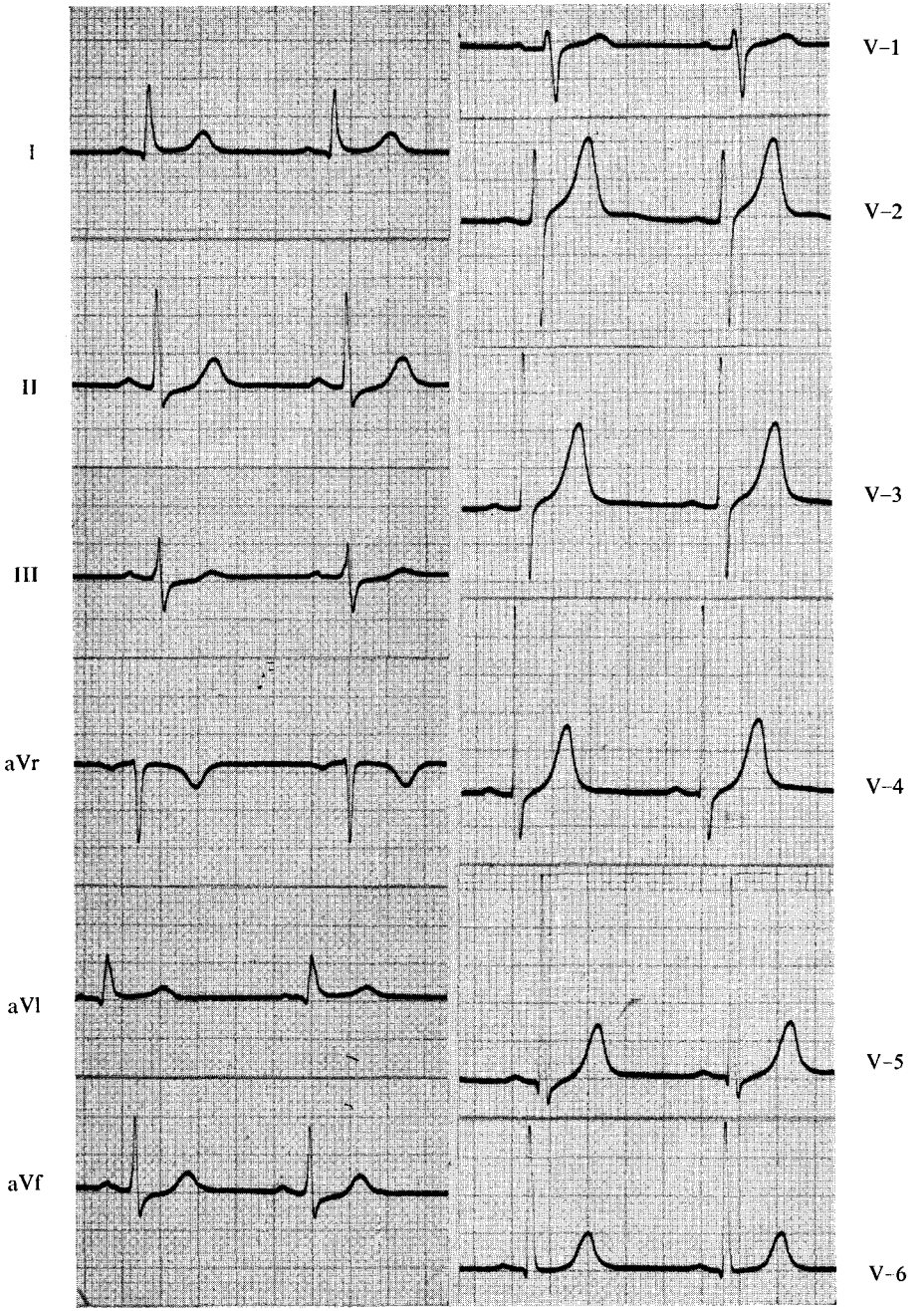


FIG. 3.9. (*a*) Normal twelve-lead electrocardiogram. Average electrical position of the heart.

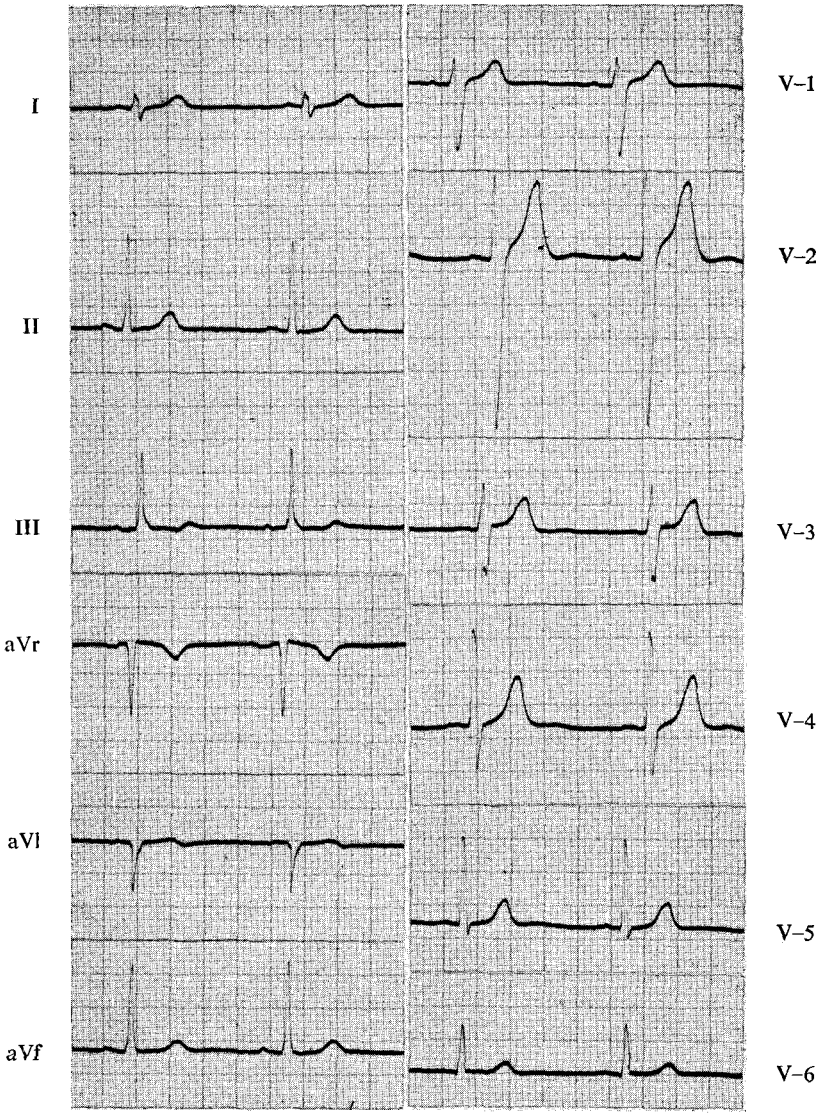


FIG. 3.9. (*b*) Normal twelve-lead electrocardiogram. Vertical electrical position of the heart. Tracing recorded from a tall, slim man, aged 18. Note in particular low R waves in lead I, high R waves in leads III and aVf, and inverted initial ventricular deflections in lead aVl.

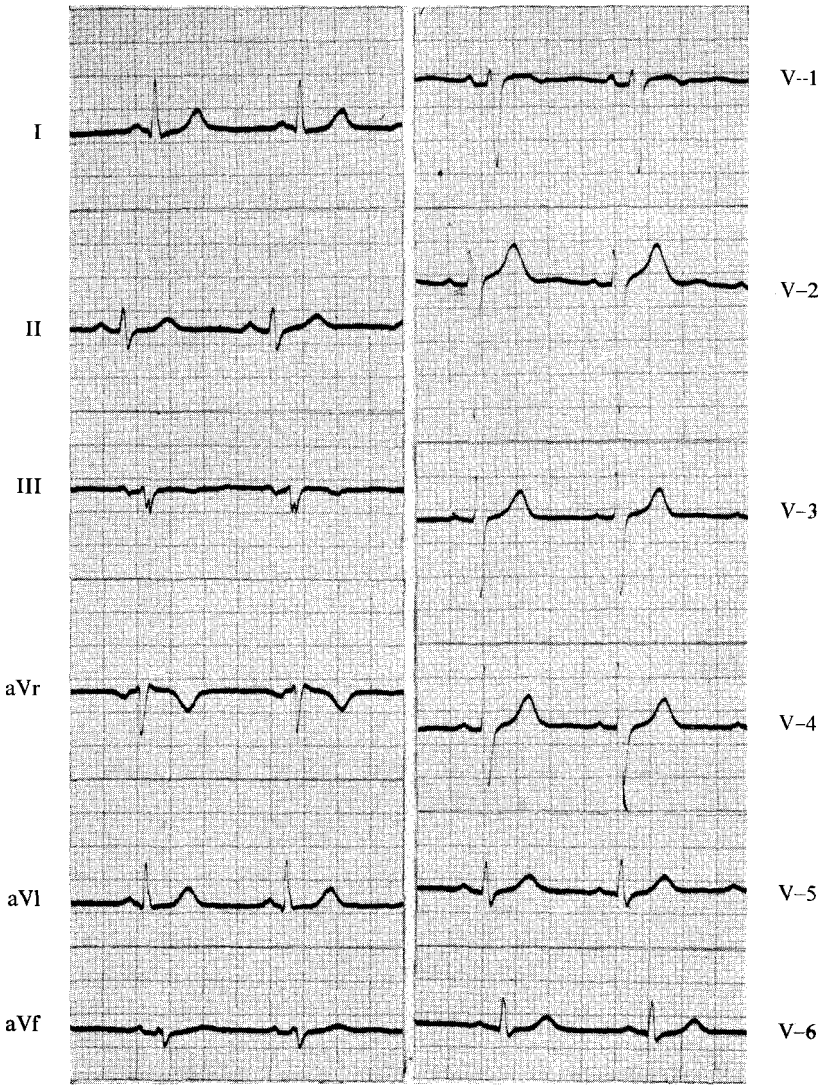


FIG. 3.9. (*c*) Normal twelve-lead electrocardiogram. Transverse (horizontal) electrical position of the heart. Tracing recorded from an obese woman, aged 45, in the thirty-fourth week of pregnancy. Note in particular comparatively high R waves in lead I, and low R and deep S waves in leads III and aVf, and comparatively high R waves in lead aVl.

these individual ones existing at that moment in the various portions of the heart (Fig. 3.10). Such resulting potential difference during excitation is called the momentary electrical axis of excitation (or depolarisation). Throughout the excitation of the heart it changes its direction and magnitude from moment to moment as the several portions of the heart muscle are being excited in quick succession. In the same manner all these *momentary* electrical axes occurring over the whole period of excitation can be represented by *one* axis, the result being called the *mean* electrical axis of excitation. Similar electrical axes can be constructed for the electrical changes during recovery from excitation, that is, the momentary and the mean axes of repolarisation. Such an axis has a certain magnitude and direction. It is, therefore, also called a vector, a vector being a quantity of definite direction and magnitude. An electrical vector has, in addition, "sense", that is polarity: it is positive at one, and negative at the other end. By con-

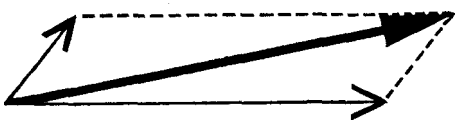


FIG. 3.10. Construction of the resultant vector from two component vectors (parallelogram of forces). The resultant vector (thick line) is the diagonal of the parallelogram constructed from the two component vectors. The same principle applies for construction of the resultant of more than two component vectors, the resultant of each such construction becoming one of the two components for the next.

vention, it is often depicted as an arrow pointing from the negative to the positive end. To quote Grant's (1950) comparison of a vector with an arrow: ". . . its length indicates the magnitude of the force, its inclination indicates the direction of the force, and the location of the arrowhead indicates the sense of orientation of electrical positivity of the force". The electrical vector—whether momentary or mean—can thus be indicated by an arrow.

The electrical events recorded by an electrocardiogram are the same whatever the lead employed. If this is borne in mind and the simplified concept of the heart as being a source of electromotive force in the centre of an equilateral triangle is accepted, it is seen that the portion of the electrical vector, as it is recorded in an individual lead, depends on the angle α between the direction of the vector and the direction of the lead (Fig. 3.11). If the direction of the vector is parallel to the direction of the lead it will be fully recorded (Fig. 3.11*a*); if the vector is at a right angle to the direction of the lead, no potential difference will be recorded in that particular lead (Fig. 3.11*b*); and with positions of the vector intermediate between these two extremes a corresponding fraction of the vector will be recorded (Fig. 3.11*c*).

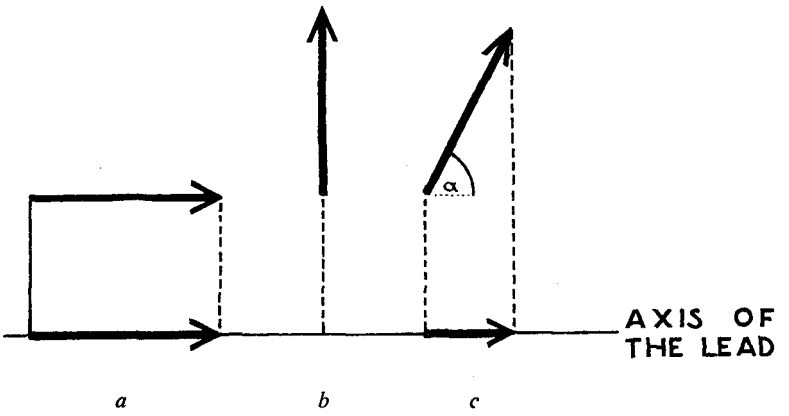


FIG. 3.11. Projection of a vector on to a lead. The vectors and their projections are shown as thick arrows. Broken lines indicate lines of projection. α = angle formed by vector with the line of the lead. (*a*): Vector parallel to the lead. (*b*): Vector at a right angle to the lead. (*c*): Intermediate position of the vector.

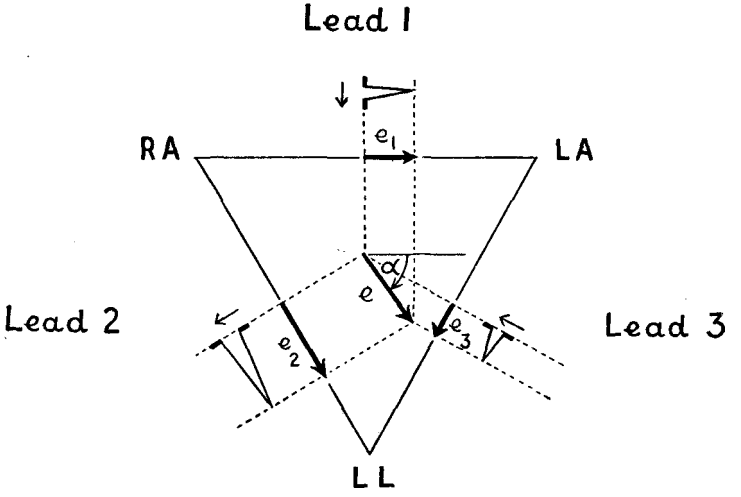


FIG. 3.12. Diagram of Einthoven's equilateral triangle. e = vector. Its direction is determined by the angle α which it forms with the horizontal (in this diagram 50°). e_1, e_2, and e_3 = the projections of e on to the lines of leads 1, 2 and 3. The heights of the deflections as recorded in these leads correspond to these projections, as indicated outside the triangle.

Fig. 3.12 illustrates the application of this relationship, indicating its practical importance for technicians. Let e represent the vector at a given moment. The fractions of the vector as recorded in the individual leads 1, 2 and 3 equal the projections e_1, e_2 and e_3, respectively, of the vector e on to the line representing the respective lead. If two leads are recorded simultaneously, the height of each wave in these two leads is known for any and the same moment. It can then be proved (geometrically or trigonometrically) that the projection of the vector e on to the line RA–LL, that is the line of lead 2, equals the algebraic sums of the projections of the vector on to the lines RA–LA (lead 1) and LA–LL (lead 3): $e_2 = e_1 + e_3$. It should be emphasised that, in an ECG,

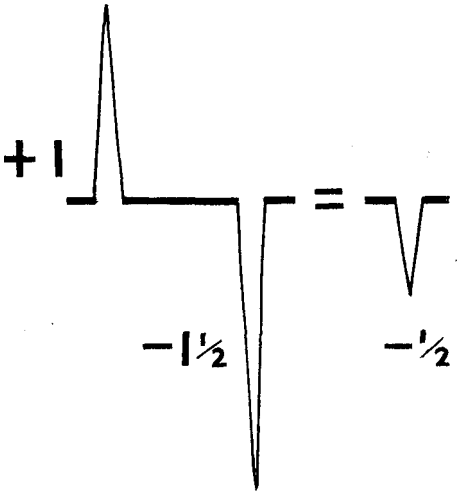


FIG. 3.13. Diagrammatic illustration of the principle of algebraic summation. The algebraic sum of a positive deflection of 1 unit and a negative deflection of 1½ units is −½. For further explanation, see text.

this equation refers to the *algebraic* summation of the heights or depths of the respective waves, upright waves having a positive, downward waves a negative sign. For example, the algebraic sum of an R wave 1 cm high in lead 1 and a simultaneous S wave 1½ cm deep in lead 3 equals −½, that is, a downward deflection (S wave) of ½ cm is recorded in lead 2 at that moment (Fig. 3.13).

The electrical axis, or vector, can be determined in this way for each of the several waves of the electrocardiogram. As already mentioned, it is necessary to record two leads simultaneously for this purpose. The reason is that an individual wave in one lead does not necessarily correspond in time with the same wave in another lead. For instance, the peak of an R wave of one lead may not only not coincide in time

with that in another lead, but may actually be inscribed at the same time in one lead in which an S wave is recorded in the other. For this reason it is not possible to calculate accurately the momentary electrical axis by algebraically summating the R or S waves in leads which were not simultaneously recorded.

In practice, however, the *approximate* determination of the electrical axis from leads not recorded at the same time is of great value from a technician's point of view. To an approximate degree the fundamental relationship: Lead 2 = Lead 1 + Lead 3 holds good also for tracings with individual leads recorded in succession. This makes it possible for technicians to prevent or trace errors in the marking and mounting of leads. Mistakes tend to occur if portions cut out from various leads are mounted to form a permanent record. If in a record of the three standard limb leads lead 2 does not approximately correspond to the algebraic sum of leads 1 and 3, some mistake in marking or mounting should be suspected.

3. The Effect upon the Electrocardiogram of the Position of the Heart

The interrelationship between the three standard leads, as exemplified by Einthoven's law, is in itself one manifestation of the influence of the position of the heart on the electrocardiogram in the three leads concerned. If Einthoven's law is applied to hearts in different positions in the body—as normally occurs as a result of different build, respiration, and other factors—additional information is obtained.

Fig. 3.14 illustrates the relationship, laid down by Einthoven's law, for different positions of the vector. If the electrical axis is almost vertical, as is apt to occur in tall thin subjects with low diaphragms, the projection e_1 of the vector e on the line of lead 1 is very small, and e_3, that on the line of lead 3, large (Fig. 3.14*a*). This indicates that electrocardiograms of subjects in whom the heart is in such a comparatively vertical position, where the angle α is relatively large, the R waves in lead 1 are small and in lead 3 high. As the angle α between the electrical axis and the horizontal becomes smaller, the projection e_1 of the vector e on to the line RA–LA (lead 1) becomes progressively larger and that of e_3 progressively smaller (Fig. 3.14*b* and *c*). Records obtained from individuals, in whom the heart lies in a comparatively transverse (or horizontal) position (angle α small), show in fact large R waves in lead 1 and small R waves in lead 3. With still smaller angles α between the vector and the horizontal, the direction of the main deflection of the QRS complexes in lead 3 becomes reversed, the projection e_3 of the vector in this instance having the opposite direction (Fig. 3.14*d*). Such tracings show in lead 3 a more or less deeply inverted main deflection of the initial ventricular complex, that is, a more or less deep S wave. They are often found in stout individuals with broad chests and high diaphragms. See also Fig. 3.9 on pp. 27–29.

These considerations emphasise the great extent to which the features in the limb leads are determined by the position of the mean electrical axis. This is illustrated in some more detail in Fig. 3.15. The heart is again assumed to lie in the centre of an equilateral triangle, and also in the centre of the sector. The figures at the outside of the sector indicate in degrees the angle formed by the mean electrical axis with the horizontal. The size of the main deflection of the QRS complexes in

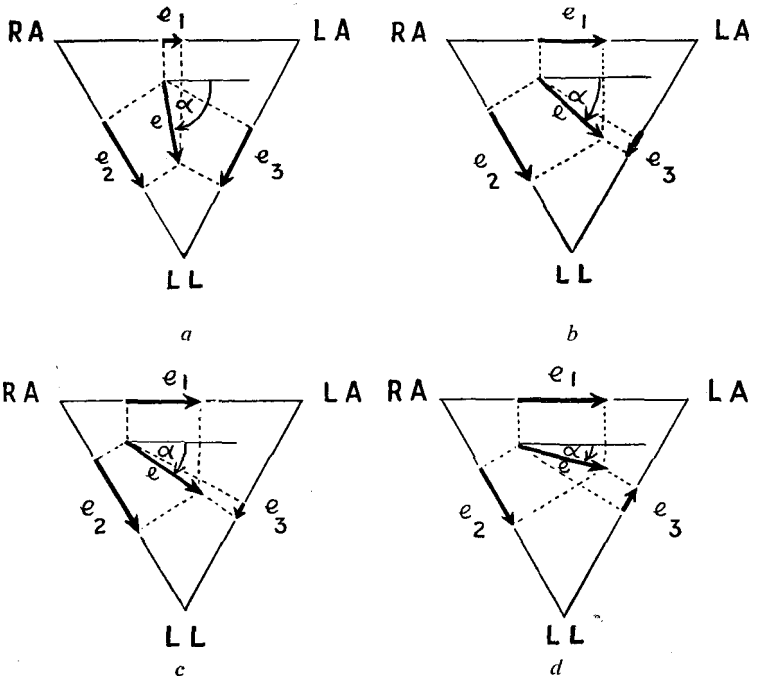


FIG. 3.14. The effect, upon the height and direction of deflections in the standard leads, of different positions of the vector. Angle α of the vector is in $a = 80°$, $b = 40°$, $c = 27°$, $d = 10°$. For further explanation, see text. Modified from Scherf and Boyd, *Clinical Electrocardiography*.

each of the standard leads is indicated by the numbers of + and − signs, + indicating an upward, − a downward deflection. It is seen from this figure that the heart is in a mid-position if the angle α is between + 30 and + 60°. A more vertical position is associated with an angle α between + 60 and + 90°, a more transverse one with angles α between + 30 and 0°. It will be noted that, as the axis varies from + 90 to 0°, the size of the main deflections of the QRS complexes increases in lead 1 (indicated in the figure by changing from − to + + +), while the changes in lead 3 are the reverse. Figures of angle α

between − 30 and + 100° comprise the range of normal. (Angles of more than + 90° are comparatively rare in normal subjects. In such cases the main deflection of the QRS complex in lead 1 is directed downward, that is, consists of an S wave which is deeper than the small upright R wave.)

No two individuals have exactly the same physical build, nor have they, therefore, identical projections of the electrical vectors on to the

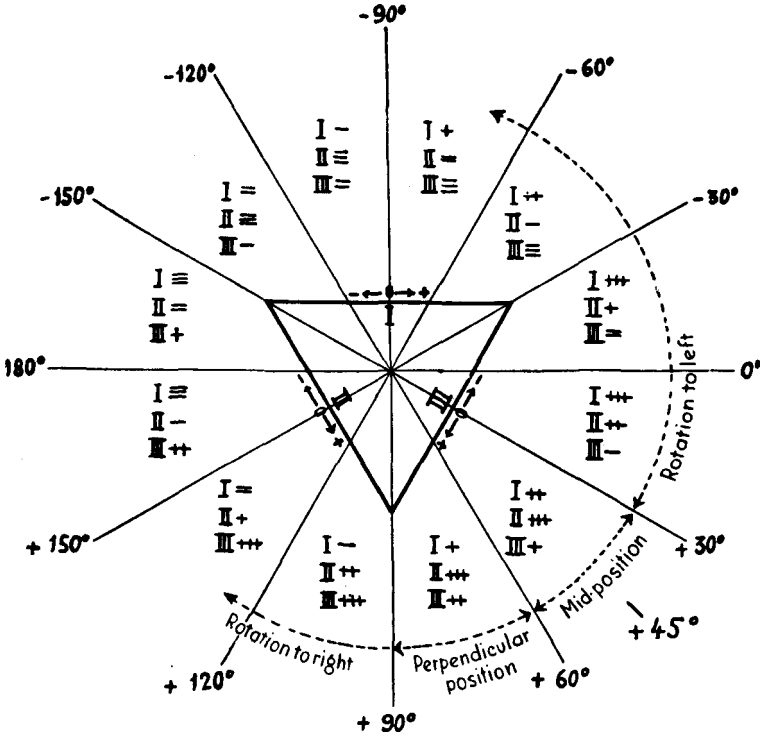


FIG. 3.15. The effect, upon the height and direction of deflections in the standard leads, of different positions of the heart. For further explanation, see text. From Holzmann, *Klinische Elektrokardiographie.*

lines from which the limb leads are recorded. It is thus understandable that no two individuals have exactly the same electrocardiograms in the various leads, if the tracings are examined in detail. The normal ranges of the height of the several waves in the various leads are summarised in tabular form in Table, I pp. 37 and 38.

Individual differences are particularly pronounced in lead 3, so that this lead has been termed the "lead of exceptions". In it the P waves are often notched, very small, absent or inverted; the QRS complexes may be small or slurred, with their main deflections directed upward,

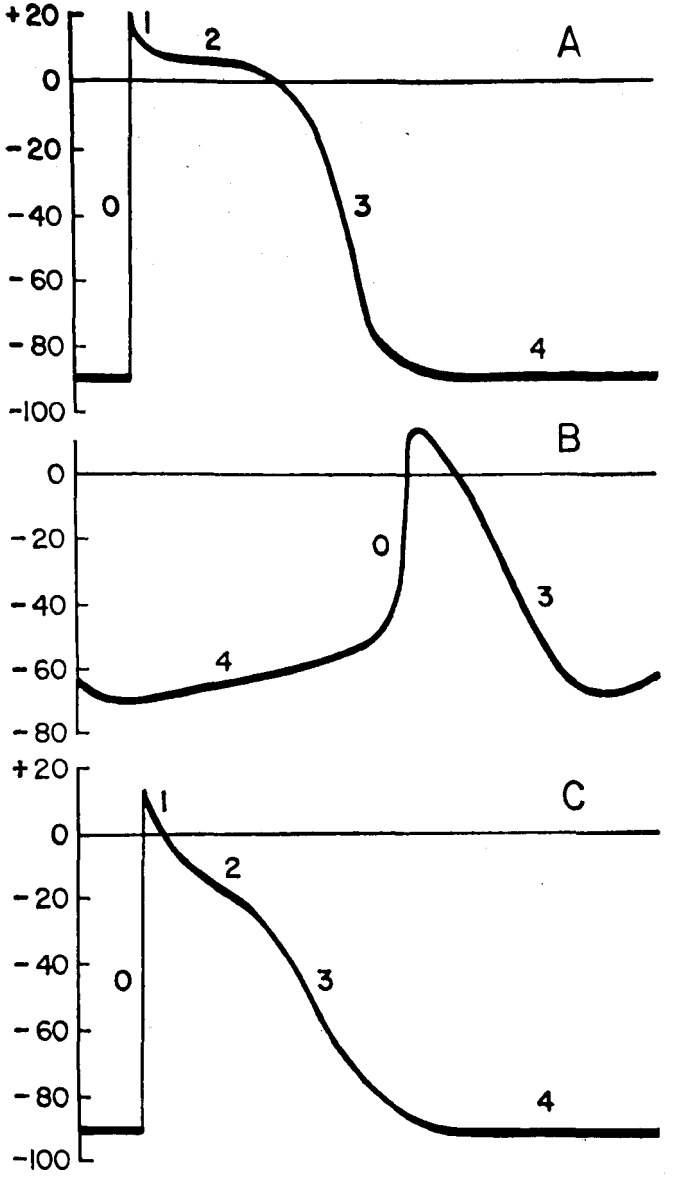


FIG. 3.16. Schematic records of transmembrane action potentials recorded from ventricle (A), sinoatrial node (B), and atrium (C). Sweep velocity in B one-half that in A and C. Ordinate scale in mv. 0 = initial rapid upstroke; 1 = early rapid repolarisation; 2 = prolonged phase of slow repolarisation ("plateau"); 3 = terminal phase of rapid repolarisation; 4 = diastolic period. From Hoffman and Cranefield, *Electrophysiology of the Heart.*

TABLE I

Upper Limits (97·5 percentile) and Lower Limits (2·5 percentile) of Limb Leads for Healthy Men and Women by Age Groups

		Men						*Women*					
		I	*II*	*III*	aV_R	aV_L	aV_F	*I*	*II*	*III*	aV_R	aV_L	aV_F
Upper limits													
	20–29 yr.	2·0	2·1	2·6	—	2·0	2·2	1·0	1·1	2·2	—	1·3	1·6
Q	30–39 yr.	1·2	1·3	2·0	—	1·3	1·3	1·1	1·3	1·6	—	0·9	1·2
	40–59 yr.	1·1	1·2	2·4	—	1·2	1·2	1·2	1·5	2·0	—	1·4	1·1
	20–29 yr.	12·9	19·1	15·8	3·2	8·3	16·9	9·5	15·9	14·5	1·8	7·2	15·6
R	30–39 yr.	11·3	17·0	12·4	2·9	8·5	14·8	15·6	15·5	12·7	2·2	9·2	13·9
	40–59 yr.	11·6	15·5	11·9	2·2	9·3	12·6	12·5	15·3	11·8	1·6	8·5	13·0
	20–29 yr.	4·0	4·8	6·0	16·1	8·7	4·9	3·2	2·9	4·3	11·6	9·2	2·1
S	30–39 yr.	4·2	4·3	8·5	12·0	6·8	4·4	2·9	3·2	4·5	14·6	4·5	2·6
	40–59 yr.	3·0	3·8	7·5	11·6	4·6	4·1	2·1	3·1	6·0	12·5	3·9	3·9
	20–29 yr.	4·1	5·8	3·0	−0·8	2·1	3·9	4·0	4·4	2·1	−0·7	2·2	3·1
T	30–39 yr.	3·7	5·0	2·9	−1·0	2·1	3·8	3·8	4·9	2·0	−0·9	3·0	3·2
	40–59 yr.	3·5	4·3	2·2	−0·8	2·2	3·1	3·2	4·1	1·7	−0·7	2·6	2·6
Lower limits													
	20–29 yr.	1·3	4·7	0·8	0	0·1	1·0	1·3	3·9	0·5	0	0·1	1·8
R	30–39 yr.	1·8	4·0	0·3	0	0	1·0	1·4	2·6	0·1	0	0·3	1·0
	40–59 yr.	2·0	1·9	0·1	0	0·2	0·3	2·0	2·6	0·1	0	0·2	0·3
	20–29 yr.	0·9	0·8	−0·9	−5·0	−0·8	−0·2	0·5	0·7	−0·7	−0·4	−0·4	−0·1
T	30–39 yr.	0·6	1·0	−1·5	−4·2	−0·8	0·4	0·9	0·6	−1·8	−3·5	0	0·1
	40–59 yr.	0·7	0·8	−1·2	−3·4	−0·5	0	0·7	0·8	−1·1	−3·6	−0·1	−0·2

Sample size for men = 115 for age 20–29 years, 110 for age 30–39 years, and 424 for age 40–59 years.
Sample size for women = 104 for age 20–29 years, 65 for age 30–39 years, and 142 for age 40–49 years.
Q and S waves in aV_R listed together under S amplitude; QS pattern in leads III, aV_L, and aV_F also listed under S amplitude.
Lower limits for Q and S waves zero in all limb leads except S–aV_R, in which it is 3·7, 3·7, and 3·2 for men and 2·4, 2·1, and 3·4 for women in each age group.
Amplitudes in mm (1 mm = 0·1 mV).

TABLE I (*contd.*)

Upper Limits (97·5 percentile) and Lower Limits (2·5 percentile) of Precordial Leads for Healthy Men and Women by Age Groups

		Men						*Women*					
		V_1	V_2	V_3	V_4	V_5	V_6	V_1	V_2	V_3	V_4	V_5	V_6
Upper limits													
	20–29 yr.	—	—	—	2·9	3·1	2·6	—	—	—	0·7	1·2	1·8
Q	30–39 yr.	—	—	—	1·7	2·0	1·6	—	—	—	1·4	1·8	1·5
	40–59 yr.	—	—	—	1·0	1·6	1·5	—	—	—	1·3	1·2	1·4
	20–29 yr.	8·9	13·9	26·6	27·7	24·0	19·3	5·3	9·2	17·5	19·6	18·7	16·3
R	30–39 yr.	5·4	12·1	22·5	29·2	24·8	18·3	5·8	10·1	23·3	25·9	22·2	20·2
	40–59 yr.	4·9	12·0	11·6	25·6	25·0	17·8	4·0	9·1	17·7	23·6	20·9	16·8
	20–29 yr.	12·1	29·1	22·0	14·9	6·4	3·7	14·2	23·2	14·2	8·9	4·0	1·8
S	30–39 yr.	17·6	27·8	22·6	12·1	6·7	2·8	14·3	19·8	11·9	7·8	3·2	1·7
	40–59 yr.	16·7	23·3	19·0	14·1	6·9	2·9	15·1	18·0	13·5	7·7	5·0	2·6
	20–29 yr.	3·9	12·3	11·7	11·8	8·1	5·9	2·0	7·1	8·6	7·5	5·5	5·0
T	30–39 yr.	3·3	11·1	11·5	9·9	7·0	4·5	1·2	7·5	7·7	7·0	5·9	4·7
	40–59 yr.	3·9	10·1	10·7	10·4	7·8	4·9	1·5	6·5	7·4	6·3	5·1	4·6
Lower limits													
	20–29 yr.	0·3	1·7	2·2	6·1	5·9	3·7	0	1·1	2·3	5·0	5·2	5·2
R	30–39 yr.	0·2	0·6	2·2	5·2	8·1	5·9	0	0·4	0·8	4·1	5·0	4·0
	40–59 yr.	0·1	0·6	1·4	4·2	5·9	4·9	0·1	0·2	1·0	3·7	5·0	3·6
	20–29 yr.	3·0	6·7	1·2	0	0	0	1·6	4·0	0·7	0	0	0
S	30–39 yr.	3·2	6·1	3·3	1·1	0	0	3·8	4·2	0·6	0	0	0
	40–59 yr.	2·9	5·2	2·7	0·8	0	0	2·3	2·4	0·5	0	0	0
	20–29 yr.	−2·2	1·1	1·9	1·5	0·8	0·5	−2·1	0	0	1·0	1·0	0·9
T	30–39 yr.	−1·4	2·0	3·1	2·0	1·3	0·8	−2·6	0	0·5	0·8	0·8	0·6
	40–59 yr.	−1·3	1·7	2·0	1·6	1·3	0·8	−1·9	0·1	0·1	1·0	0·9	0·7

Sample size for men = 115 for age 20–29 years, 110 for age 30–39 years, and 424 for age 40–59 years.
Sample size for women = 104 for age 20–29 years, 65 for age 30–39 years, and 142 for age 40–59 years.
QS pattern in V_1 included in S amplitude.
Lower limit for Q wave zero in all chest leads.
Amplitudes in mm (1 mm = 0·1 mV).

Adapted from Simonson, *Differentiation between Normal and Abnormal in Electrocardiography*.

or downward, or both, and the T waves upright, absent or inverted. Sometimes lead 3 taken while the patient is holding his breath in maximum inspiration yields valuable diagnostic information. In these cases lead 3 is taken twice, during normal respiration and during respiratory standstill in maximum inspiration. This practice is carried out as a routine in some hospitals.

The unipolar limb leads also are greatly influenced by the position of the heart, which they help to determine more accurately. On the whole, in the augmented unipolar right arm lead aVR the P waves are inverted, the R waves very low or absent, the S waves deep and T waves inverted. This is due to the fact that this lead indicates the changes of potential in the region of the right shoulder, that is, of a point from which the excitation spreads away (see p. 8). Great individual differences are also found in the augmented unipolar left arm (aVL) and left leg (aVF) leads, due to different positions of the heart. See also Fig. 3.9 on pp. 27–29.

All limb leads are particularly affected by changes in position of the heart round the antero-posterior axis, that is an imaginary line drawn through the body from front to back.

In the chest leads the deflections are often larger than in the limb ones. In chest leads obtained from points 1 and 2, which in most cases means that they were recorded over the right heart, the P waves are well defined and the S waves are larger than the R waves. In leads recorded from points 5 and 6, that is in most cases from over the left heart, high R and small S waves are found as a rule. Leads from points 3 and 4 show features intermediate between those from points 1 and 2, and 5 and 6, respectively. The T waves are upright in all chest leads in most adults. They are sometimes inverted in V–1 and this is the rule in children in whom the T waves in V–2 and occasionally also in V–3 may be inverted, or partly inverted and partly upright.

The features of the chest leads are largely influenced by the position of the heart in relation to its long axis; this is an imaginary line drawn from the base to the apex, which runs from above, right and backward in a direction downward, to the left and forward.

Another important positional factor determining the electrocardiogram of normal hearts is respiration. With the descent of the diaphragm during inspiration the heart assumes a more vertical position. During expiration the reverse occurs.

The purpose of these remarks is to provide some approach to the appreciation of the wide variations between normal records and to demonstrate some of the factors underlying them. The recognition of the limits of normality and the distinction, in an individual case, between normal and abnormal features requires correlation of the electrocardiogram with clinical findings. It therefore necessitates medical training and is outside the scope of the technician.

APPENDIX

The more recent investigations, referred to on p. 7, were made by means of very small electrodes, less than 1/1,000 mm in diameter, introduced under a microscope into the interior of a heart muscle cell, and paired with a second electrode on its surface. The electrode inside the cell records the intracellular potentials, which are amplified and recorded by specially designed amplifiers and recording apparatus. As soon as the electrode pierces the cell membrane of a resting heart muscle fibre and reaches the interior of the cell, a potential difference across the cell membrane of 80–90 millivolts is recorded, negative in the interior with respect to the external reference electrode. This is called the resting transmembrane potential, which indicates that the cell membrane is "polarised". When the cell is stimulated, the action potential is recorded (see Fig. 3.16). This produces a sharp rise in the tracing, indicating that the potential difference between the interior and exterior not only has disappeared and the cell thus has become "depolarised", but that the potential difference is momentarily reversed, so that the interior of the cell becomes temporarily positive by about 20 millivolts. This reversal is called "overshoot". Subsequently, this disappears, the electrical potentials inside and outside the cell becoming equal (the duration of this "plateau" phase varying in different parts of the heart). Then the potential difference between interior and exterior is gradually restored, that is, the cell membrane becomes "repolarised", with the negativity inside the cell. The duration of the whole action potential is 0·2–0·5 second in the mammalian heart, varying in different species and with temperature. While the cell is in the resting condition, the tracing records a straight line, indicating a steady resting transmembrane potential, except in cells of pacemakers. These show a slow reduction in intracellular negativity, that is, a slow depolarisation, during diastole, preceding the abrupt upstroke at the beginning of electrical systole (see Fig. 3.16B).

REFERENCES

Cunningham, D. J. (1951). *Textbook of Anatomy*. Edit. by J. C. Brash. 9th ed. Oxford University Press, London, New York, Toronto.

Einthoven, W. (1908). "Weiteres über das Elektrokardiogramm." *Pflüg. Arch. ges. Physiol.*, **122**, 517.

Einthoven, W., Fahr, G., and de Waart, A. (1913). "Uber die Richtung und die manifeste Grösse der Potentialschwankungen im menschlichen Herzen und über den Einfluss der Herzlage auf die Form des Elektrokardiogramms." *Pflüg. Arch. ges. Physiol.*, **150**, 275.

Goldberger, E. (1942). "A simple, indifferent electrocardiographic electrode of zero potential and a technique of obtaining augmented, unipolar, extremity leads." *Amer. Heart J.*, **23**, 483.

Grant, R. P. (1950). "Spatial vector electrocardiography. A method for calculating the spatial electrical vectors of the heart from conventional leads." *Circulation*, **2**, 676.

Hoffman, B. F., and Cranefield, P. F. (1960). *Electrophysiology of the Heart.* McGraw-Hill Book Company, New York, Toronto, London.

Holzmann, M. (1961). *Klinische Elektrokardiographie.* 4th ed. Thieme, Stuttgart.

Kiss, F., and Szentágothai, J. (1960). *Atlas of Human Anatomy.* Publishing House of the Hungarian Academy of Sciences, Budapest.

Mitchell, G. A. G., and Patterson, E. L. (1954). *Basic Anatomy.* E. & S. Livingstone Ltd., Edinburgh and London.

Scherf, D., and Boyd, L. J. (1953). *Clinical Electrocardiography.* 4th ed. Heinemann, London.

Simonson, E. (1961). *Differentiation between Normal and Abnormal in Electrocardiography.* C. V. Mosby Company, St. Louis.

Wilson, F. N., Johnston, F. D., Macleod, A. G., and Barker, P. S. (1934). "Electrocardiograms that represent the potential variations of a single electrode." *Amer. Heart J.*, **9**, 447.

Wilson, F. N., Johnston, F. D., Rosenbaum, F. F., Erlanger, H., Kossmann, C. E., Hecht, H., Cotrim, N., de Oliveira, R. M., Scarsi, R., and Barker, P. S. (1944). "The precordial electrocardiogram." *Amer. Heart J.*, **27**, 19.

CHAPTER 4

THE STRING ELECTROCARDIOGRAPH

THE string electrocardiograph is no longer widely used, but has been chosen to introduce the instrumentation side of electrocardiography, since it explains the principles involved without complication. The complete equipment comprises:

(*a*) String galvanometer and optical projection system;
(*b*) Illuminating system;
(*c*) Recording camera;
(*d*) Time-marker;
(*e*) Control and standardising panel;
(*f*) Electrodes.

Fig. 4.1 shows in diagrammatic form the general arrangement of the components. Each of these is described briefly under its respective heading.

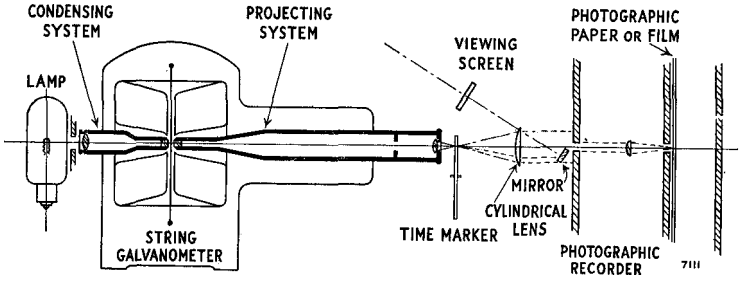


FIG. 4.1. Diagram of the general arrangement of the components of a string electrocardiograph.

String Galvanometer and Optical Projection System

The string galvanometer is the essential part of the outfit. It comprises a powerful magnet between the poles of which is stretched a fine, gold-plated, glass "string" of 0·004 mm diameter, and an optical system designed to illuminate the string and magnify its projected image 600 times. The purpose of the gold plating is to make the glass string electrically conducting.

Illuminating System

A powerful electric lamp provides the illumination, the light from which is condensed by the optical system to provide a concentrated and even illumination of the string on to the face of a recording camera.

Recording Camera

The camera consists of a motor arranged to drive, at even speed, a strip of photographic paper or film past an aperture.

The string image appears in front of the camera as a vertical shadow about 3 mm wide, and is condensed by a cylindrical camera lens to become a dark spot in the band of light which falls on to the photographic film or paper. Thus, if the film or paper is moving at right angles to the movements of the string, it will record an image showing the movements of the dark spot in the light band.

To produce horizontal markings on the records for calibration purposes, the cylindrical lens in front of the camera aperture is marked along its length by lines at 1 mm intervals, which produce shadows that are also photographed on the moving film. The film speed is normally set at 25 mm/sec., although faster speeds are sometimes desirable (e.g. in the recording of phonocardiograms).

Time Marker

A rotating spoked wheel interrupts the projected light beam so that a series of vertical white lines are photographed. The wheel is usually provided with five spokes, and is made to rotate exactly five times per second. One of the spokes is wider than the remaining four, hence time lines will appear at intervals of 1/25th sec., with a thick line each 1/5th sec. This enables the intervals between the recorded wave-forms to be measured accurately.

Control and Standardising Panel

Connections to the patient are made through a control board which embodies a selector switch for obtaining the correct electrode connections in the desired sequence. The leads are fully explained above (pp. 21–26); see also pp. 86–89.

Prior to recording the various leads of the electrocardiogram it is necessary to standardise the instrument, that is, test and, if necessary, adjust the tension of the string so that the galvanometer will yield a known deflection for a given input signal. It is normally arranged to give 10 mm deflection for an injected signal of 1 millivolt. The signal is provided from an internally fitted battery. In practice, depressing a knob (or switch) on the control panel applies the 1 millivolt signal, and the tension of the string is adjusted by means of a knob at the side of the galvanometer.

In some cases of exceptionally large excursions it is customary to standardise at 5 mm for 1 millivolt.

The patient selector switch is generally in the form of a knob which is rotated first to "standardise", followed by the various lead positions. Each lead should be calibrated separately and the calibration deflection recorded.

Superimposed on the varying currents due to the heart action there is usually a relatively large and fairly steady potential due to the glandular activities of the skin, known as "skin current". It may be either positive or negative in polarity and the polarity may change from lead to lead. The skin current provides an unwanted signal and this should be eliminated in one of several ways which will not be discussed in detail.

Electrodes

Many forms of electrodes have been designed for the connection of the wires from the electrocardiograph to the patient. The importance of careful electrode application cannot be overemphasised, see Chapter 7.

Principle of Operation

When a current passes down the "string", the string is deflected at right angles to the magnetic field. If the direction of the current is reversed, the string will move in the opposite direction. These movements are proportional to the current flowing and are inversely proportional to the tension applied to the string. By making the string as light as possible and using powerful magnets, the sensitivity of the instrument is made sufficiently high accurately to respond to the small varying currents associated with cardiac activity.

The essential characteristics of all cardiographic recorders is that the period of the moving system should be such that it will faithfully follow the rate of change in heart potential and that the deflection per unit current be linear and dead beat at all cardiographic frequencies. The approximate range of cardiographic frequencies lies between 5 and 80 per second. The string galvanometer has these desirable characteristics.

CHAPTER 5

VALVE-OPERATED CARDIOGRAPHS

DIRECT writing instruments have almost completely replaced the string electrocardiograph for routine cardiography. These offer distinct advantages, being compact, robust yet light, easy to operate, and producing tracings which are immediately available without any photographic processing, except instruments with an oscillographic recording system (see p. 51), which need photographic processing.

The rapid advance in direct writing electrocardiographs has been made possible by the development of amplifying techniques which can amplify the weak impulses generated by the heart to such an extent that more robust galvanometers can be employed without loss of accuracy. The first instruments used valves for such amplification. More recently, transistorised instruments have come into use and these will be dealt with in a separate chapter.

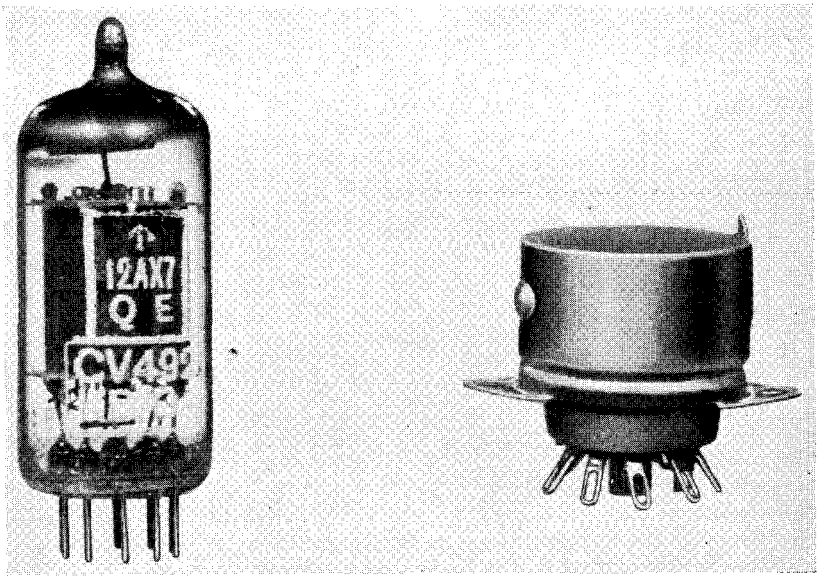
The signal voltage picked up from the patient is extremely small and must be amplified greatly in any form of electronic cardiograph. The signal is in the order of 1 or 2 millivolts at a power of about one ten thousandths part of a millionth of a watt (10^{-10} watt). As a matter of interest this means that it would require the electrical output of some ten thousand million people, or over three times the entire population of the world (1962), to light a small torch bulb!

THE VALVE

Before proceeding with a description of electronic instruments it may be useful briefly to examine the principles upon which a valve operates.

Physical Construction

A valve is essentially a glass envelope, from which all the air has been evacuated, rather similar to a cylindrically shaped electric lamp, but instead of the two wires supporting the filament, several specially shaped plates are supported on wires which are cemented into the base. In the case of an electric lamp, the connections for the filament are brought through the base and blobs of solder are left in place to connect with the pins in the socket, into which the lamp is fitted. In the case of the valve, however, the connections for the various internal plates are brought through the base and soldered to pins, the latter forming suitable terminations which can be pushed into a valve-holder.



a *b*

FIG. 5.1. (*a*) Valve typical of those used in electrocardiographs. (*b*) Valve holder.

External connections to the valve are soldered to metal tags on the underside of the valve holder. Fig. 5.1 illustrates a valve and valve-holder typical of those used in electrocardiographs.

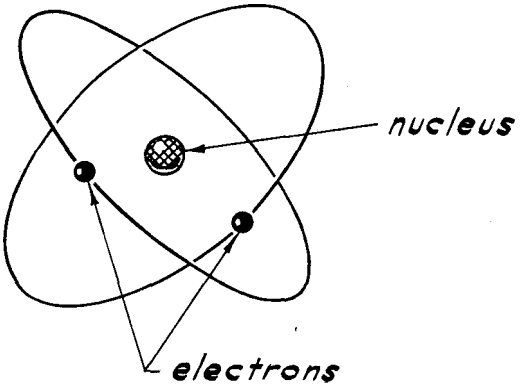


FIG. 5.2. Orbital arrangement of electrons around the positive nucleus of an atom.

Some Fundamental Principles of Electron Theory

All matter, whether solid, liquid or gaseous, is made up of extremely minute particles called molecules. Molecules can be broken down into smaller particles called atoms, and it is the way in which these combine which determine the actual composition of matter. An atom in its simplest form comprises a positively charged nucleus around which a number of negatively charged particles, termed electrons, revolve in orbits similar to our own planetary system (Fig. 5.2).

If certain types of material are heated, the electrons become extremely agitated, are released from the substance and hover over it, forming a negatively charged cloud of electrons. This happens in the valve where the substance is a coating on one of the electrodes.

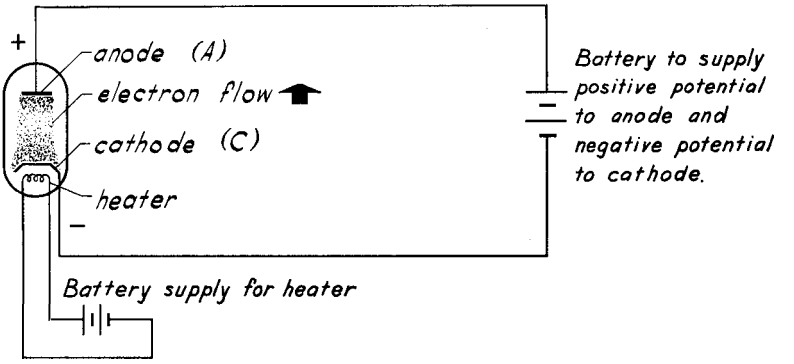


FIG. 5.3. Principle of operation of a diode valve.

Operation of a Valve

The simplest type of valve has two plates, called electrodes, one being the negative electrode termed *cathode*, the other being the positive one termed *anode*. This form of valve is known as a "*diode*". The cathode is the source of the electrons necessary for the operation of the valve and, as mentioned above, the cathode material must be heated in order to release electrons. A small filament heated by a low voltage supply carries out this function. It should be borne in mind that electrons are negative and, furthermore, that two negatively charged particles or two positively charged ones will repel each other and, conversely, that a positively and a negatively charged particle will attract each other. If a positive potential is applied to the anode, electrons will be attracted to it and a current established within the valve. Furthermore, if an external circuit is completed between the anode and the cathode a current will flow in the external circuit. The current flow can be quite large and is maintained by the steady supply of electrons from the cathode. Fig. 5.3 shows the principle of this simple two-electrode valve.

The diode is used in electronic circuits as a device to change alternating current into direct current, i.e. as a "rectifier". Reference to Fig. 5.3 will indicate that the current flows in the external circuit only when the electrode (A) is positive. This holds good also when an alternating current is applied between the anode and cathode and current will, therefore, flow only on the positive half cycles; since the current flows in one direction only it is said to be "rectified".

The Amplifying Valve

The majority of the valves in the circuit of an electrocardiograph operate as amplifying devices. In its simplest form an amplifying valve

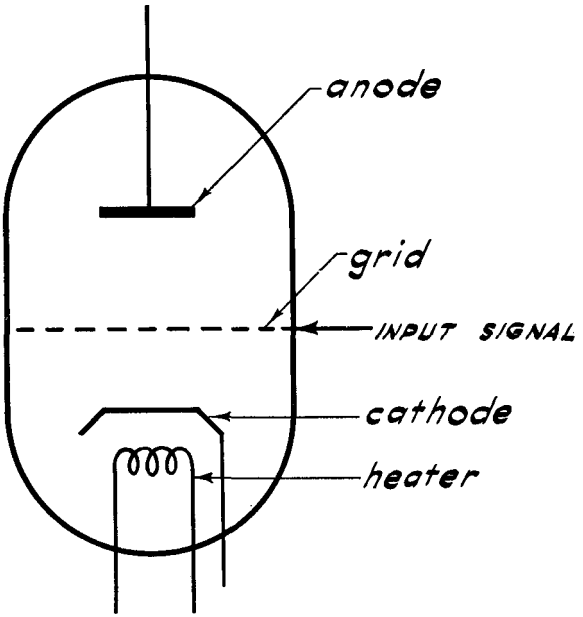


FIG. 5.4. (*a*) Diagrammatic illustration of a triode valve.

has three electrodes, two being similar to those in the diode, i.e. anode and cathode; the third electrode is called the *grid* and is positioned between the other two. The grid is constructed in the form of a fine wire mesh through which electrons can pass freely. A valve having three electrodes is called a "*triode*". Fig. 5.4*a* is a diagrammatic illustration of a triode, Fig. 5.4*b* shows its constructional details.

As mentioned previously, a positive anode is necessary to encourage the flow of electrons through the valve and hence in the external circuit. It follows that if the original anode is given a negative potential no current will flow, the electrons being repelled back to the cathode. In

practice, the "anode" is not made negative but the potential of the grid is made negative and, since the grid is positioned between the anode and the cathode, it repels some, but not all, of the electrons flowing

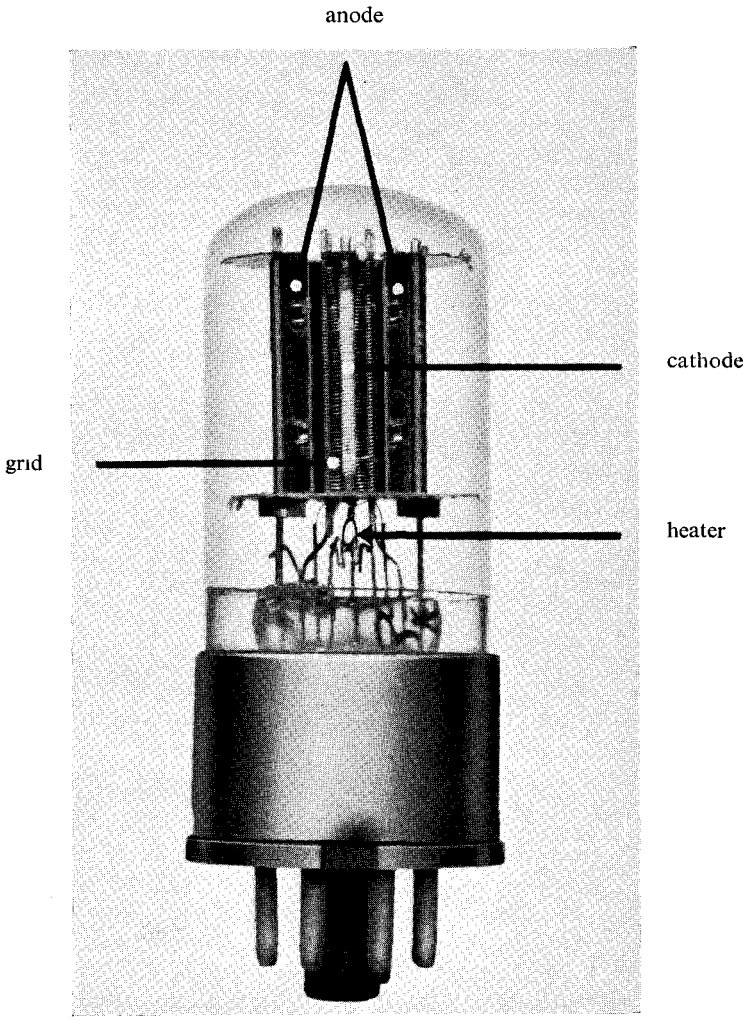


FIG 5.4. (*b*) Constructional details of a triode valve.

from the cathode to the anode. The current through the valve can therefore be controlled by making the grid more or less negative. The grid is nearer to the cathode than to the anode, and a small variation in its negative potential will cause a much larger variation in the

current flow through the external circuit. This is the basis of the amplifying characteristic of the valve. The signal is applied to the grid and thus amplified in the external anode-cathode circuit. The amplifying properties of the valve are, therefore, represented by the ratio of voltage changes in the external circuit and voltage changes of the signal. The voltage variations in the external circuit are fed into the grid of a following valve and, since the signal in the second valve is much larger, the changes in the external circuit of the second valve will be proportionately larger. In this way several valves can be made to "feed" into each other, the original small signal, e.g. from the patient, being eventually amplified to a large signal capable of moving a pen writing device.

The above explanation is much simplified. Some references for further study are given at the end of this chapter.

COMPONENT PARTS OF VALVE-OPERATED CARDIOGRAPHS

General Principles

All electrocardiographs of this type essentially consist of three components:

(*a*) the amplifier;
(*b*) the recording mechanism;
(*c*) the standardising and control panel.

All are operated from an alternating current supply; connection to a direct-current supply must be avoided as serious damage to the instrument will almost certainly result.

The Amplifier

It is not proposed to refer in detail to the circuits of the amplifiers contained in these instruments since they are many and varied, and all manufacturers have their own ideas and requirements which they may be reluctant to disclose in detail. Suffice it to say that the work of designing and developing these circuits is considerable and difficult, since each designer is of necessity governed by the characteristics of the recording mechanism employed.

The prime requirements are the same as those described for the string instrument—that is: The ultimate amplified characteristics should be linear over the range of cardiographic frequencies at the requisite sensitivity of 10 mm for 1 millivolt with the patient in circuit; the deflection time of the recording pen should not exceed 1/80th second; and the recording system be dead beat. Some of the difficulties in designing a system with these characteristics are briefly discussed in an appendix to this chapter. From this appendix it will become apparent

why the user should refrain from tampering with, or trying to readjust the circuits or replace components, with the possible exception of replacing a valve by its exact equivalent and no other. "The nearest equivalent available at the moment" should never be considered. It is not enough to get the outfit working; it must have the same required characteristics at all times. Some makers stock complete replacement amplifying units and recording units, which may easily be fitted by the technician. The defective unit should be returned to the manufacturer for test and replacement or repair.

Valve-operated instruments, in common with string instruments, are equally affected by alternating current interference and by somatic tremor; regarding their elimination see pp. 92 and 94 respectively.

Recording Mechanism

Oscillographic Recorders

These instruments employ a moving system consisting of a single loop of wire carrying a small mirror, which is enclosed in a strong magnetic field and provides a recording unit of high sensitivity and frequency response. Oscillograph galvanometers are energised by an amplifying system similar to that already described.

The method is, with one exception, a photographic one. A beam of light is focussed on to the mirror, from which it is reflected on to photographic paper contained in a camera, similar to that described for the string cardiograph (p. 43). A current applied to the loop of wire causes the latter to twist a small amount, owing to the interaction between the resulting magnetic field in the loop and that of the original magnetic field, the motion being proportional to the magnitude of the applied signal. Thus the twisting motion of the loop causes the mirror to deflect the light beam across the camera aperture, the movements of the mirror being recorded on the photographic paper as it moves past the aperture. The resulting record has to be developed in a dark room. The exception is the instrument employing the fluid jet method of recording, in which the oscillograph mirror is replaced by a fine jet nozzle (p. 53).

The main advantages are that the galvanometer moving systems are so light that the resonant frequency can be well outside the cardiographic frequency band, that they have a linear response up to about 600 cycles per second, and that almost any number of units can be employed, side by side, to obtain simultaneous tracings. These recorders are widely used for heart sound recording (see p. 113).

Direct-Writing Recorders

There are many forms of direct-writing recorders employed with valve cardiographs. The more common types are:

(*a*) Pen writing with special ink;
(*b*) Pen consisting of a heated stylus;
(*c*) Fine capillary with fluid jet.

The movement employed for deflecting the pen writing system under (*a*) and (*b*) is a galvanometer of the moving coil pattern, the principle of operation being as follows:

A coil of many turns of wire, wound in the shape of a rectangle, is pivoted in a strong and uniform magnetic field. Helical control springs are provided at the pivot points to ensure that the coil takes up a definite position—known as the "mechanical zero". If a current is fed into the coil, a magnetic field is set up around it and this field interacts with that of the original magnetic field. The resulting forces cause the coil to rotate, the degree of rotation being determined by the ratio of the input current to the control exerted by the springs. With no input current the control springs return the coil to its mechanical zero. The pen is attached to the coil and any movement of the coil will, therefore, cause the pen to deflect.

Pen with Special Ink

This consists of a specially designed pen carried on the galvanometer pointer or arm and usually terminating in a fine glass capillary. The end of the capillary rests lightly on the moving paper strip and acts as a pen, the ink being fed from a reservoir connected to the capillary. In such records the surface tension of the ink used is of great importance, and only that supplied or recommended by the makers of the instrument should be employed. The use of ordinary ink should be avoided, even in an emergency, as it would immediately choke the fine capillary and render the pen ineffective. The correct ink or dye is usually composed of a spirit base to hasten drying of the record, and also to facilitate the free flow of the ink. The paper is of a special quality to suit the ink employed. The pens, which are often easily removable from the galvanometer boom, may periodically be cleaned in pure spirit or weak acid. The capillary should be blown out occasionally, as it can become choked by foreign matter picked up from the surface of the recording paper.

Pen with Heated Stylus

These are of two forms: in one, the stylus is a point of sapphire that is heated by surrounding it with a fine winding of wire through which an electric current is passed; in the other, a fine hairpin-like loop of electrically-heated wire rests upon the paper. The latter is more commonly used, the wire loop usually being one of the pure metals, such as platinum, with high melting point and durability. These pens require a special form of heat-sensitive paper, which consists of a black

base coated with a white oxide. The effect of contact with the heated point is to volatilise the white covering so that the black base is made visible in the track of the moving hot wire loop. The heat of the stylus is adjustable and the width and density of the recorded tracing can thereby be varied within wide limits. These pens require cleaning from time to time, as they tend to scrape up the decomposed oxide covering, which forms a heat insulating layer on the pen loop. This cleaning can be done by gently rubbing the point with a fine camel-hair brush, and sometimes it is desirable to wash with the brush dipped in spirit. Another effective way of cleaning the point is to stroke it gently with a small piece of fine grade emery paper. Such cleaning must be done with the pen cold (that is, the instrument must be switched off). Great care should be taken not to damage the pivoted galvanometer movement to which the pen is attached. Pens of the electrically heated type occasionally burn out, or become brittle and break. Replacements can be supplied by the makers and may usually be fitted by a competent technician; some skill is required, otherwise the galvanometer may become unbalanced and its linearity affected.

Fine Capillary with Fluid Jet

This form of recorder consists of a nozzle of fine capillary, fitted direct to the moving loop of an oscillograph system, from which an extremely fine jet of liquid dye is projected under pressure on to an absorbent paper. In this case there is no direct contact with the recording paper, and thus any pen-paper friction is avoided. The liquid is of a special nature and is carried in a reservoir from which the pen is fed. The great advantage is that the moving system is very light and dead beat, and that resonance effects may be ignored. It is capable of linear frequency response up to about 600 cycles per second and will record frequencies up to 900 cycles per second with some loss of response; it is therefore suitable for phono- as well as electrocardiographic recording.

It will be realised that each of these methods of recording requires its own special recording paper, and none other than that supplied by the makers should be employed.

All recording papers used with these instruments are pre-printed with time markings, and it is therefore essential that the driving motor be of an accurately adjusted constant speed. In case of doubt regarding the speed of paper feed, one rough check is to arrange for a live A.C. electric cable, such as that supplying an electric lamp, to be run parallel and adjacent to the patient lead. This will probably introduce on a recorded baseline an interference wave of the same frequency as that of the electric supply. In Great Britain this is usually 50 cycles per second, so each cycle, or positive and negative peaks, of that wave will occur at 1/50th second. These peaks can be compared with the time

lines, over a length of record strip, and should remain coincidental, i.e. 50 peaks should fit exactly 25 of the vertical time lines 1 mm apart (Fig. 5.5). In U.S.A. the frequency is mostly 60 cycles per second and calculation over a period must be resorted to as the peaks would no longer coincide. Another simple but effective check is to allow the paper chart to run for, say, 30 seconds and then measure the length of paper fed out; in this example, for a normal paper drive speed of 25 mm per second it should be $25 \times 30 = 750$ mm, or approximately 29·5 inches (1 inch = 25·4 mm). There is no automatic check provided by the makers, as the motors are usually of the synchronous type and may be relied upon to have constant speed. One factor that may affect paper speed is slip between the paper and drive rollers, but usually this can be observed as a jerky movement. If any doubt remains after checking the paper speed as described, the makers should be consulted.

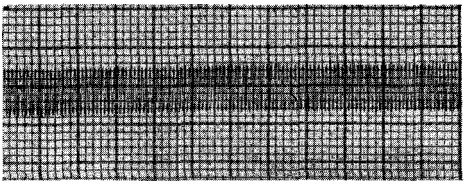


FIG. 5.5. Fifty cycle wave for checking paper speed.

The Standardising and Control Panel

The control panel of electronic instruments usually incorporates the following:

(*a*) Mains connection switch;
(*b*) Selector switch for lead connections;
(*c*) Standardising switch;
(*d*) Amplitude control;
(*e*) Tracing thickness control;
(*f*) ON/OFF switch for recording motor;
(*g*) Zero position control;
(*h*) Interference eliminator;
(*i*) Fuse plate.

The following additional facilities are sometimes provided:

(i) Half sensitivity switch;
(ii) Record marking device;
(iii) Variable speed control for chart drive;
(iv) Separate earth connection;
(v) Muscle tremor suppressor.

Mains Connection

All valve instruments are operated from A.C. mains. The mains supply should be checked to ensure that it is A.C. and NOT D.C., and that the connection employed is correct for the mains voltage. In countries where the frequency of the supply varies in different localities, this also must be checked. If the supply is not correct the instrument will not function accurately and may be damaged. Electronic instruments should never be connected to direct current mains and great care should be taken to prevent this happening. It is particularly necessary to check this when the instrument is used where the electric supply is unknown.

In some outfits, closure of the instrument lid automatically disconnects the mains supply.

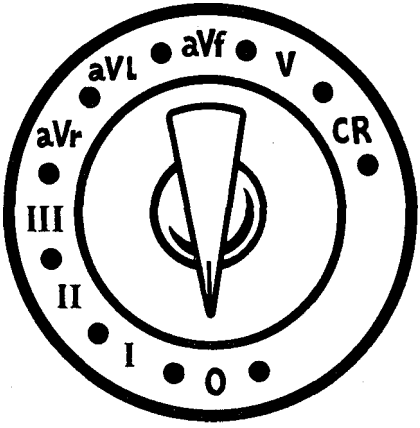


FIG. 5.6. Lead selector switch (semi-diagrammatic).

Selector Switch

This switch is usually provided with a zero or calibrating position, and with points for the lead connections in the established sequence (Fig. 5.6).

Standardising Switch

This is used in conjunction with the amplitude control in order that the galvanometer may be adjusted to give a deflection of 10 mm for

1 millivolt. The standardising voltage is applied by depressing a push-button or operating a conventional switch.

Tracing Thickness Control

In those instruments which employ the hot stylus method of recording, a rheostat controls the stylus temperature. It will generally be found that best results are obtained if the heat is such that it causes a barely visible dull red glow at the pen tip. Too little heat will give rise to thin, indistinct tracings, and too much, to broad diffused records (Fig. 5.7). On instruments employing the fluid jet writing system a

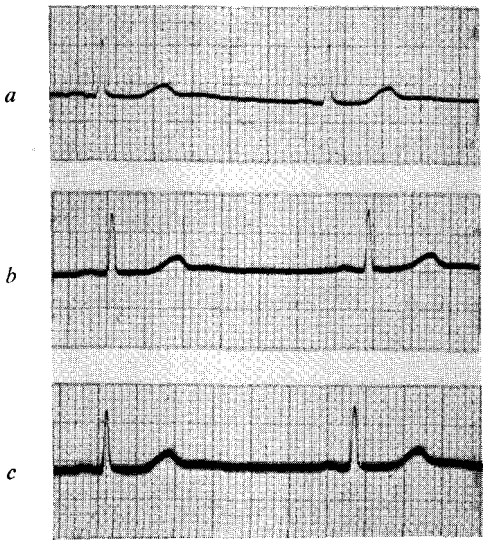


Fig. 5.7. Effect on tracing of varying stylus heat: (*a*) too little, (*b*) correct amount, (*c*) too much heat.

control to vary the fluid flow is provided. In all cases tracings with a baseline width of about 0·5 to 1 mm are considered to be the most satisfactory.

Zero Position Adjustment

This is provided to offset the zero position of the pen to one side or the other so that large positive or negative deflections can be fully recorded within the limited width of the paper.

Interference Eliminator

This may take one of several forms depending upon the design incorporated by the manufacturers. The manual eliminator enables the operator to inject a signal equal in magnitude but opposite in phase to that causing the interference, and controls are provided for this (see Fig. 5.8). Some instruments incorporate an automatic system for detecting the interference which is then phase inverted and fed back to the input of the amplifier, thus counteracting the effects of the interference before it reaches the recording system.

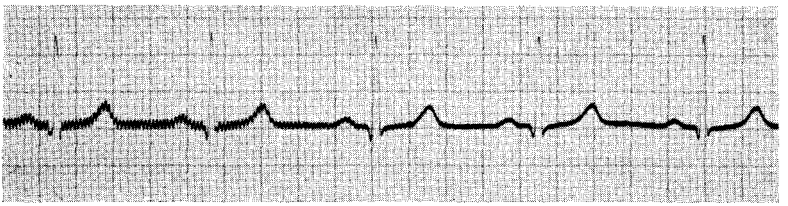


Fig. 5.8. Elimination of A.C. interference by manual eliminator.

Fuse Plate

This varies with each type of outfit, but will be adequately explained by the makers' instructions. Replacement fuses should be kept in stock.

Half Sensitivity Switch

This switch makes it possible to halve the sensitivity of the instrument without the necessity of re-standardising it. This is particularly useful when recording chest leads which, in some patients, yield deflections much too large to be accommodated in the width of the paper if recorded with the usual sensitivity.

Record Marking Device

Many forms of this device are in use, ranging from a simple push button causing a line to appear on the edge of the recording paper to instruments which print a symbol representing the lead being taken. In the case of the push button it is necessary to establish a code of dashes or dots or a combination of both to indicate the lead recorded.

Details of such a code are largely a matter of personal preference. One example is reproduced below:

Lead	*Symbol*
I	—
II	— —
III	— — —
aVr	–
aVl	– –
aVf	– – –
V1	– —
V2	– — —
V3	– — — —
V4	– — — — —
V5	– — — — — —
V6	– — — — — — —

Variable Speed Control for Chart Drive

This feature is incorporated in some instruments and provides facilities for two or more paper speeds. A higher paper drive speed of 50 mm per second is sometimes useful for spreading the record and hence facilitating the measurement of time intervals, e.g. when recording electrocardiograms on patients with fast heart rates.

Separate Earth Connection

Modern instruments are usually earthed via the third or earth wire of the three-wire mains system, but if a separate earth connection is provided, the makers' instructions as to its use should be followed.

Muscle Tremor Suppressor

Some instruments are provided with a means for suppressing the interference signal due to muscle tremor. Its use arises in cases of uncontrollable tremor, e.g. due to senility or certain diseases of the patient. This device may be particularly useful in cases where recording from shoulders and groins (see p. 80) failed to provide an undistorted tracing.

Electronic instruments do not need any form of compensation for skin current as all direct current is effectively blocked in the amplifier. This blocking may cause a vigorous deflection of the pen when switching from one lead to another, and it is therefore advisable to follow the makers' instructions regarding the time which must elapse between lead selections. Recently considerable improvements have been made and in some instruments the blocking time, as it is termed, has been made

negligible, so that lead switching can be carried out rapidly without pen wander.

Care should be taken to ensure that the instrument is switched off and disconnected when not in use. If this is not done and an instrument is left connected for considerable periods it may overheat, especially if the lid is closed; this seriously shortens the effective life of the valves. It is for this reason that some makers fit a switch that automatically switches off the instrument when the lid is closed.

Figs. 5.9 and 5.10 illustrate two examples of modern valve-operated cardiographs.

APPENDIX

Electrocardiography has developed into an exact science, and it has become recognised that small departures from the norm may be of great significance. The technical questions posed are:

(*a*) Is the amplified power sufficient to eliminate any changes due to pen friction or varying surface of the recording paper?
(*b*) Is the response linear over the range of cardiographic frequencies?
(*c*) What is the effect of valve deterioration with time?
(*d*) Do resonance effects of the moving system materially affect the electrocardiogram?

Point (*a*) can be answered categorically in the affirmative, as there is no reasonable limit to the power amplification factor except that which is dictated by size, weight and cost of the apparatus.

Point (*b*) presents more difficulty, since the amplification factor is, to some degree, dependent upon the frequency of the impulse, and this becomes more difficult when the impulses are of relatively low frequency. There is no absolute check of frequency linearity, fitted to any instrument, that can be applied by a technician, and this characteristic must therefore be taken on trust.

Point (*c*) is a matter of great clinical importance and at the same time of some technical difficulty. Valve emission is bound to deteriorate with use, but careful design of the circuit can ensure that the amplifier will fail in such a manner that valve failure is apparent and the nature of the trouble likely to be suspected. Failure to record or gross instability of the baseline are two kinds of such manifestations which may be quoted as examples.

Point (*d*). Unlike the string galvanometer, which may be considered inertialess, direct writing cardiographs employ a robust recording system having considerable mass, which is bound to have a point of resonance in the frequency band. If this resonant frequency falls within the cardiographic frequency band, it will tend to distort and unduly amplify any deflections that take place at this frequency. Ideally the

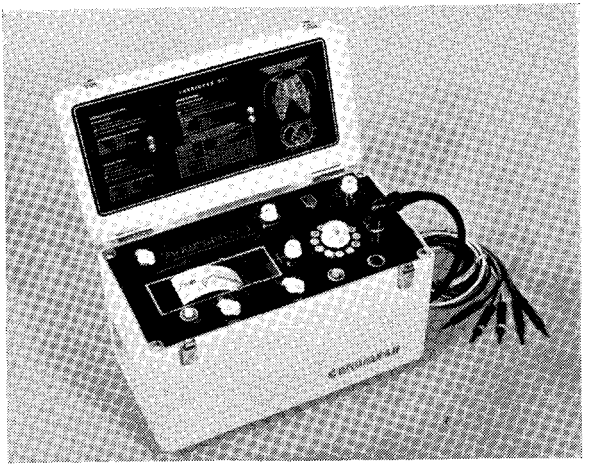


FIG. 5.9. Instrument manufactured by Philips Electrical Ltd., using heated stylus method of recording.

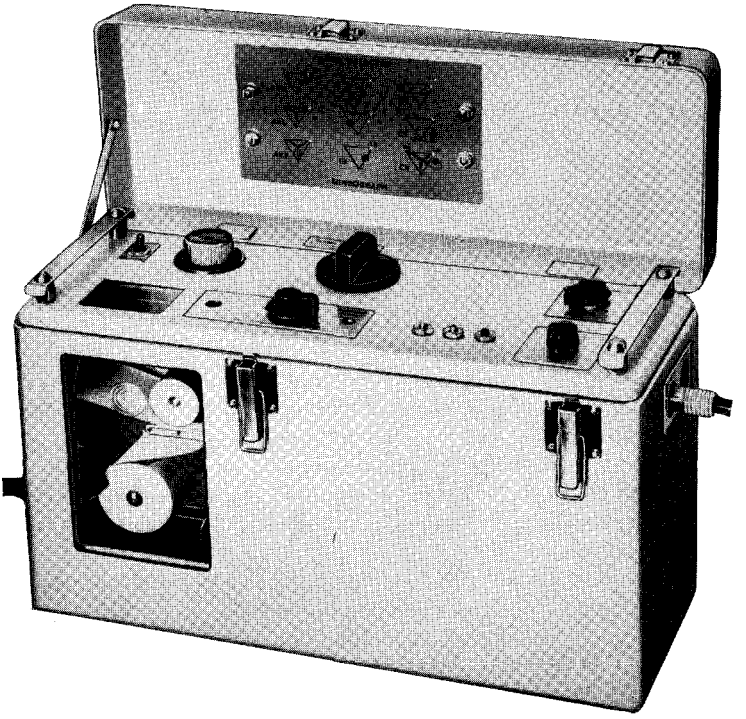


FIG. 5.10. Instrument manufactured by Messrs. Elema-Schönander (Sweden), using fluid jet recording system.

resonant frequency should be well outside the limits of cardiographic frequencies, but in practice it usually lies within or near this range, thus seriously disturbing the linearity factor. The lack of linearity so caused is usually offset, as far as is possible, by so designing the amplifier that the amplification factor is less around the resonant frequency, which tends to straighten out the linearity curve. Obviously, it is not possible to do this with exactness, but it can be sufficiently well done to conform with practical requirements. Any disturbance of this finely balanced effect in the amplifier is likely to give rise to quantitative errors in amplitudes at certain frequencies and the resulting curves suffer some distortion.

The object of these remarks is to make clear that the design of these systems is not a straightforward matter, and that much time and expense has been incurred to produce the established and well-proven models that are at present in use.

RECOMMENDED BOOKS FOR FURTHER STUDY

Agger, L. T. (1955). *Principles of Electronics*, 2nd ed. Macmillan, London.
Stead, G., and Allsopp, C. B. (1961). *Elementary Physics*, 10th ed. Churchill, London.
Van Valkenburgh, Nooger and Neville, Inc. (1961). *Basic Electronics*, Parts 1 and 2 (of six parts), 2nd ed. The Technical Press, London.
Whitfield, I. C. (1960). *An Introduction to Electronics for Physiological Workers*, 2nd ed. Macmillan, London.

CHAPTER 6

TRANSISTOR-OPERATED CARDIOGRAPHS

THE advent of transistors has heralded a marked advance in the design of electrocardiographs and enabled direct writing instruments to be further reduced in size and weight while, at the same time, being more robust and reliable.

Before describing the transistor electrocardiograph, the principles upon which a transistor operates will briefly be examined. A complete understanding of the subject demands an extensive knowledge of physics and consequently the following explanation has been greatly simplified.

While it is not strictly correct to compare the mode of operation of a transistor with that of a valve, some comparison in general terms is possible which may help to explain the principle involved. In accordance with the sequence adopted in the section for the valve, the semiconductor diode will first be considered, followed by a description of the transistor.

SEMICONDUCTORS

Semiconductors, as the name suggests, are partial conductors. The process of preparing the substances used in the construction of these devices is extremely involved. Suffice it to say that initially the material has to be of the highest possible purity and complicated processes to achieve this aim have been evolved. Germanium and silicon are widely used in the construction of semiconductor devices. In their pure state, however, these substances are insulators and, after purifying, it is necessary to add a minute, carefully controlled, quantity of an impurity, e.g. arsenic or indium, in order that the substances may act as semiconductors.

Like a valve, semiconductor devices depend for their action on the movement of electrons, but whereas in a valve the movement is in a vacuum, in the case of a semiconductor the electron movement is in the solid mass of the material. This results in a device which is mechanically stronger and in consequence more robust. Furthermore, since plenty of current carriers are available at normal room temperature, a semiconductor, as distinct from a valve, does not require a heater, i.e. a separate battery supply; consequently the device is less subject to deterioration and failure due to drop in emission.

In a semiconductor device, current is carried by positive carriers as

well as by negative electrons, the positive carriers being referred to as "holes". The predominance of holes or the predominance of electrons in the semiconductor material is determined by the type of impurity added (e.g. indium produces an excess of holes, arsenic an excess of electrons). Material in which holes are more numerous is called p-type, "p" standing for positive, material in which electrons are more numerous is called n-type where "n" stands for negative.

Semiconductor Diode

The first semiconductor diode was a point-contact type which consisted of a tungsten wire touching the surface of a germanium crystal.

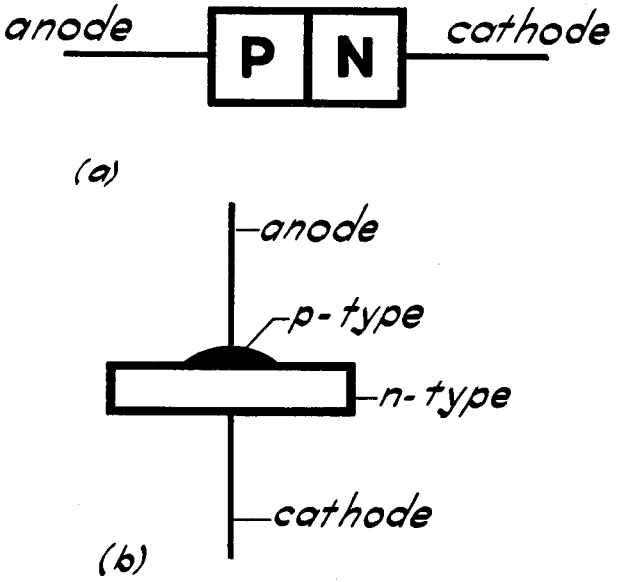


FIG. 6.1. (*a*) Sandwich arrangement of p-n materials; (*b*) construction of junction diode.

It is a modern version of the "cat's whisker" crystal used in the earliest wireless receivers. This form of diode is particularly useful for high frequency applications but of little interest in connection with electrocardiograph amplifier design.

More recently the junction-diode has been developed and this is the type commonly used in electrocardiograph manufacture. The junction-diode consists of a p-type and an n-type material bonded together (Fig. 6.1 (*a*)). Either germanium or silicon can be used. Wires are attached to the respective materials to form the anode and cathode (Fig. 6.1 (*b*)).

As in the case of a diode valve, current will only flow through a semiconductor diode if the correct polarity is observed, consequently it is used as a rectifier of alternating current. This device is often incorporated in the power supply unit of mains-operated transistor electrocardiographs to provide the necessary direct current supply for the transistors.

The Transistor

Junction transistors are constructed as a three-layer sandwich in the form of p-n-p or n-p-n type materials (Fig. 6.2 (*a*) and (*b*)). The three layers are respectively referred to as the "emitter", the "collector" and the "base" of the transistor, the centre portion being the base and the emitter and collector arranged on either side. Wires are attached to each layer to enable the external voltages and signal voltage to be applied (Fig. 6.2 (*c*)). It should be understood that the collector and

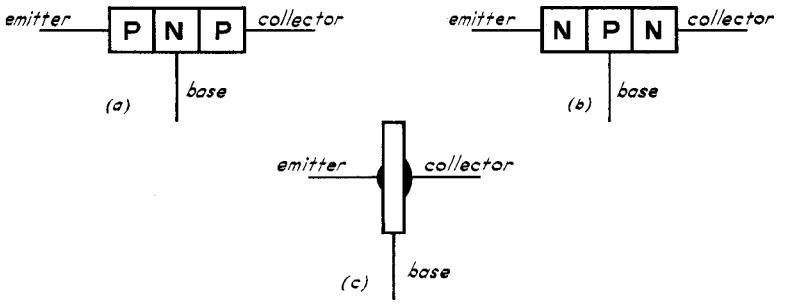


FIG. 6.2. Sandwich arrangement of (*a*) p-n-p and (*b*) n-p-n materials; (*c*) construction of a junction transistor.

emitter are fused into the base in a complicated manufacturing process and that the base is a very thin slice of material.

The collector is roughly twice the size of the emitter, the reason for this being that greater activity takes place in the collector-base region of the transistor and a larger area of collector gives the most satisfactory and efficient performance.

The emitter corresponds roughly to the cathode of a valve and acts as a source of current carriers, i.e. either electrons or positive carriers depending on the composition of the transistor. The carriers from the emitter flow into the base of the transistor and thence into the collector; thus, the collector corresponds to the anode of a valve, provided that the correct voltage polarity is observed. Not all the carriers flowing from the emitter reach the collector, a small proportion are absorbed into the base, the deficiency being made up by the flow of a very small current from the base (to the collector). If a circuit is so arranged that this small base current is varied by means of an incoming signal voltage,

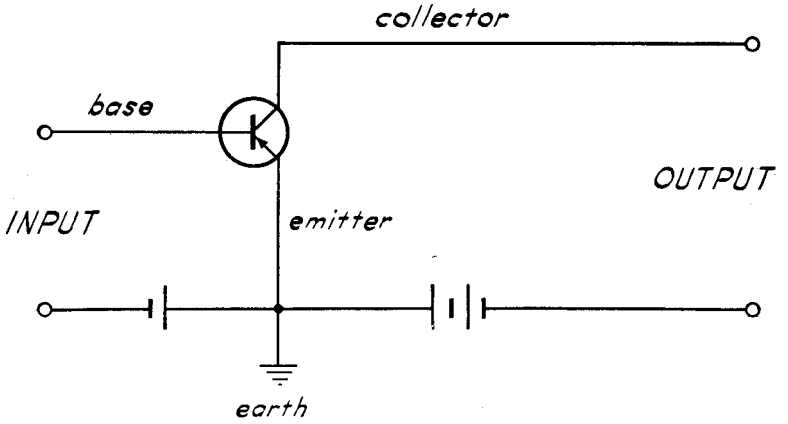


FIG. 6.3. Grounded emitter circuit for a transistor.

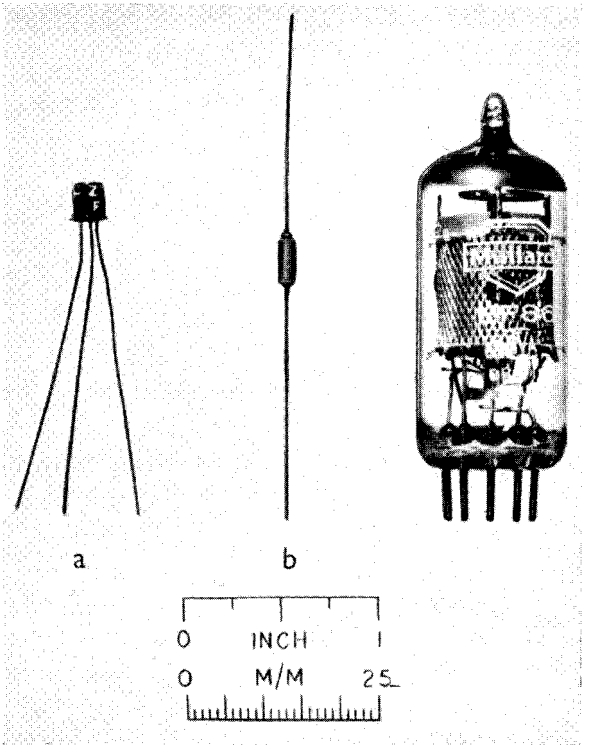


FIG. 6.4. (*a*) Transistor and (*b*) junction diode, compared for size with a miniature valve used in electrocardiograph manufacture.

the flow of carriers to the collector is modified in a controlled and predictable manner. Since a small variation in the base current causes a much larger variation in the collector current an amplification is obtained, in a manner similar to that by which the grid controls the current in an electronic valve; hence, for our purposes, we may regard the base connection as corresponding to the grid connection in a valve. The above holds for a given method of voltage connection, or biasing as it is called. Fig. 6.3 shows one method of transistor connection in which the above requirement is met.

The input signal is applied to the base and the amplified output signal is taken from the collector, the emitter is connected to earth. Since the emitter is common to the input and output circuits, the arrangement is known as a "common emitter" or "grounded emitter" circuit. Other methods are employed for connecting up transistors, for example, the grounded base arrangement, in which case the input signal is applied to the emitter. In the design of an amplifier more than one method of connection may be used to achieve the required amplification and stability characteristics.

As in the case of valves, a transistor amplifying stage may "feed" a succeeding one, the amplified current obtained from one transistor circuit being fed into the next and this process is continued until sufficient power is available to operate the recording mechanism of an electrocardiograph.

The slices of material used in the construction of a semiconductor device are very small and consequently the overall size of a transistor is much reduced compared with even a small valve. Fig. 6.4 illustrates a transistor and a diode in common use compared for size with a miniature valve of the type used in valve operated electrocardiographs.

COMPONENT PARTS OF TRANSISTOR CARDIOGRAPHS

General Principles

In general, electrocardiographs of this type consist of the same three basic components used in the construction of valve operated instruments, i.e.:

(*a*) The Amplifier;
(*b*) The Recording Mechanism;
(*c*) The Standardising and Control Panel.

The Amplifier

The essential requirements of a transistor amplifier and the problems associated with its design are, with one exception, similar to those described for the valve amplifier. The exception is the effect temperature may have on transistors. High temperatures cause transistors to become

unstable and this applies particularly to those constructed with germanium; though operating satisfactorily in temperate climates, they become unsatisfactory in tropical countries. This problem has been overcome by using silicon transistors, which are less affected by temperature, and also by the careful design of amplifier circuits to compensate for these effects.

The transistor electrocardiograph can be designed to operate from a self-contained battery supply or, alternatively, from an alternating current supply, i.e. mains-operated. Instruments have also been designed that can be powered by either batteries or by A.C. mains. This is achieved by providing a mains unit that can be interchanged with the battery box or, alternatively, by switching the battery supply to a mains input circuit.

Junction transistors are by their nature low impedance devices, that is, the impedance of an amplifier to an input signal is low. It is, however, essential that the ratio of the input impedance of the amplifier to the impedance of the signal source should be as large as practicable in order to minimise the effect of variations in skin-electrode resistance. Early instruments of the transistor type suffered from this drawback and, in consequence, hybrid instruments were developed in which both valves and transistors were used. Valves were incorporated in the first stage of the amplifier to raise the input impedance and so get over the problem of low input impedance. By the use of improved circuit techniques, however, transistor circuits have now been designed that give a satisfactory input impedance up to 10 megohms (10 million ohms) or more.

In battery-operated instruments the power required must be kept to a minimum so that batteries of reasonable capacity can be used. The reason for this becomes clear when it is realised that the capacity of a battery is usually related to its size and weight, i.e. the greater the capacity needed, the larger a battery must be. Since transistors normally operate at low voltages, about 6 or 9 volts, and since they require no current for a heater, the amplifier in battery-operated instruments is usually entirely composed of transistors. The batteries can be of the rechargeable type or, alternatively, dry batteries, similar to those fitted in transistor radios.

The advantages offered by battery-operated instruments to physicians and technicians are many. For example: they are a great asset to those living in remote areas where a mains supply may be either non-existent or unreliable; with domiciliary visits, it obviates the necessity to search for a mains outlet or earth connection, or to check the form of mains supply; only the patient lead needs connection. Furthermore, they are less susceptible to some forms of A.C. interference, as a mains cable is not brought close to the instrument and no transformer is used.

A further advance in electrocardiograph design is the use of a preformed circuit, known as a printed circuit. In this, the usual wire con-

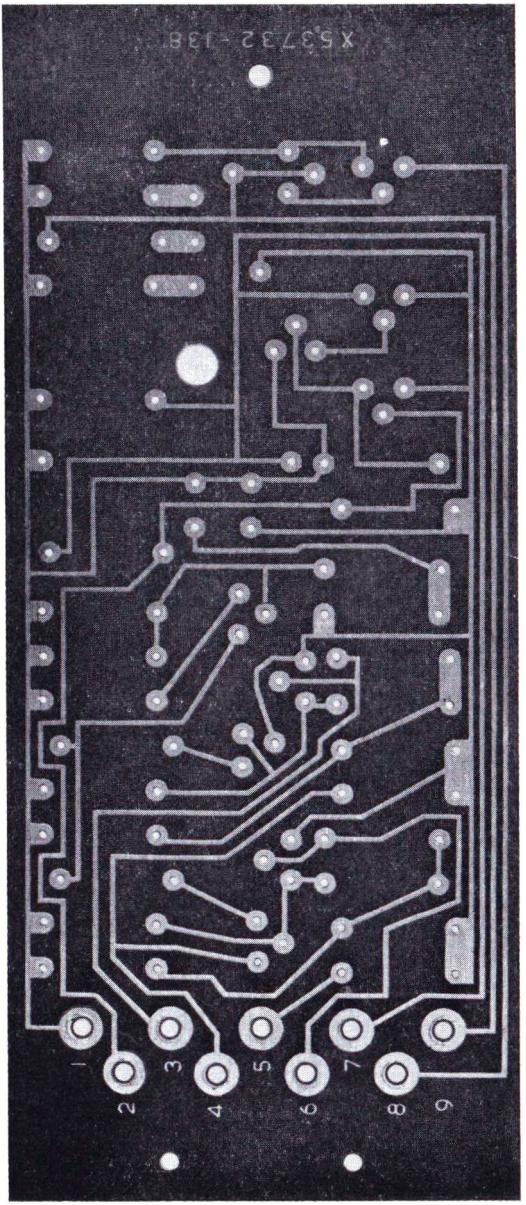


FIG. 6.5. (*a*) Plain printed circuit board.

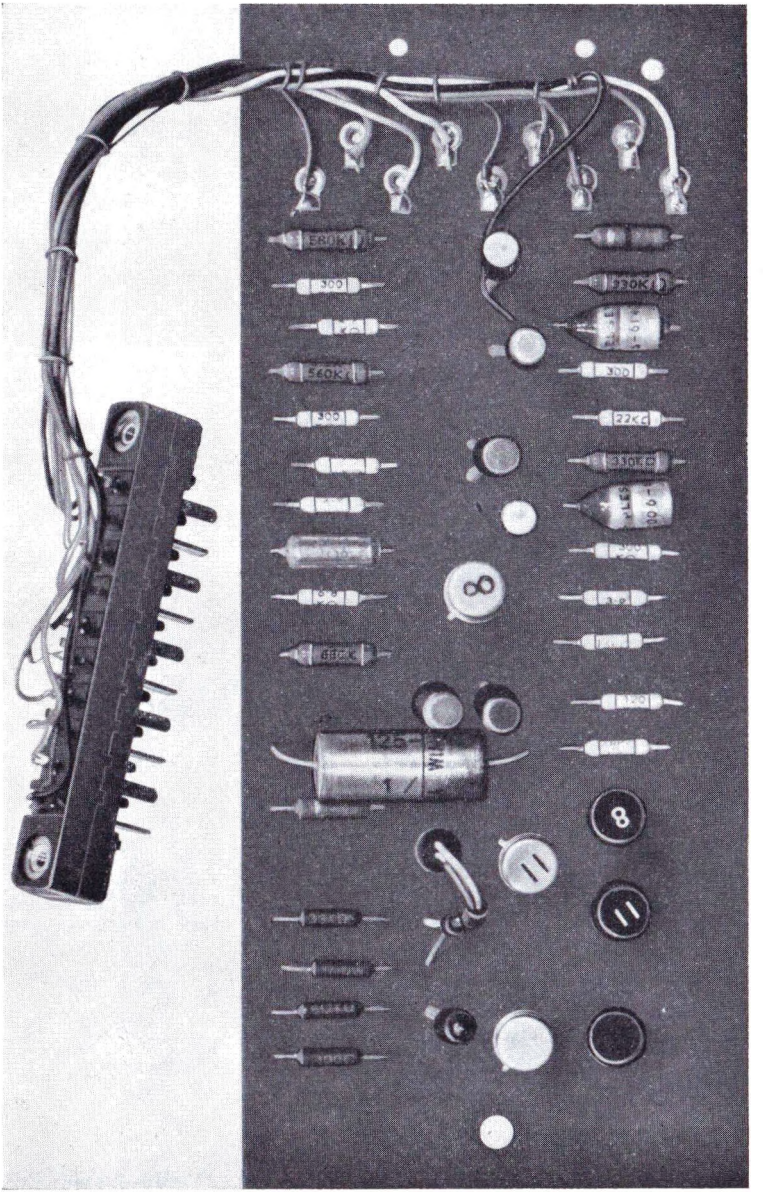


FIG. 6.5. (*b*) Components mounted ready for soldering.

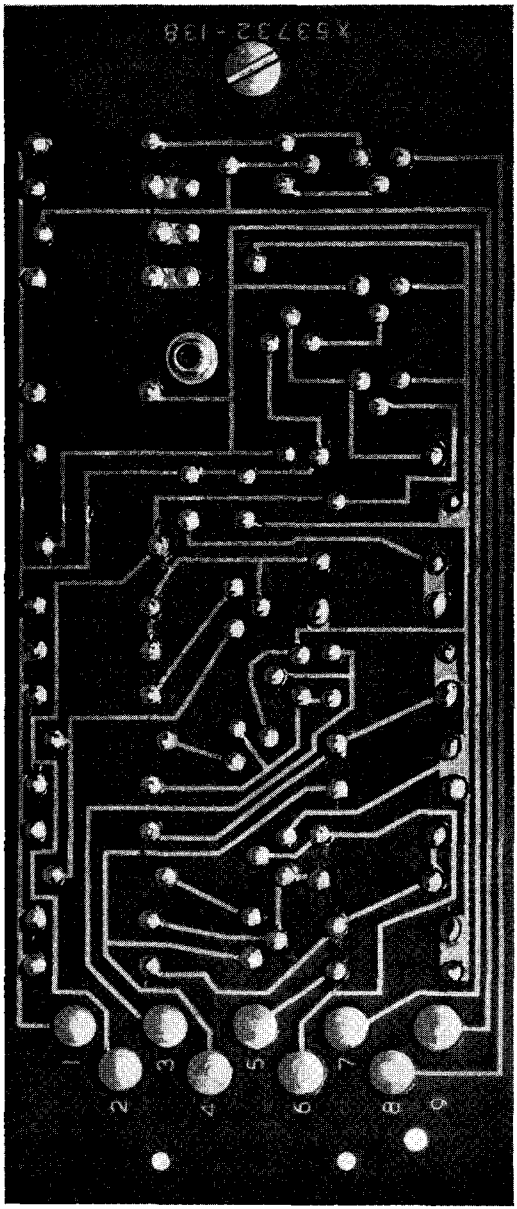


FIG. 6.5. (*c*) Soldered connections.

nections between components are dispensed with; instead, the connections are in the form of copper strips laid out on one side of a non-conducting board. Various methods of manufacture are used for the production of a printed circuit, but basically they all consist of a very thin copper sheet firmly fixed to one side of a relatively thick board of non-conducting material, the latter being approximately $\frac{1}{8}$ inch (3 mm) thick. The required circuit is reproduced on the surface of the copper film and the surplus material is removed by a special process, leaving only the strips of copper forming the circuit (Fig. 6.5*a*). Holes are drilled through the board at the points where the components are to be mounted. The various components, i.e. resistors, capacitors, transistors, etc., are mounted on the plain side of the insulating board (Fig. 6.5*b*). The leads from the components are now brought through the holes and soldered to the copper (Fig. 6.5*c*). This form of circuit is very suitable for connecting up transistors, as those used in the construction of electrocardiograph amplifiers are not generally of the "plug in" variety but need soldered connections.

As will be readily understood, this form of amplifier must be serviced by the makers. A complete amplifier can usually be replaced with little trouble and the defective amplifier taken away for repair by the makers.

Recording Mechanism

The heated stylus method of recording, as previously described (p. 52), is at present used on transistor instruments, although it is

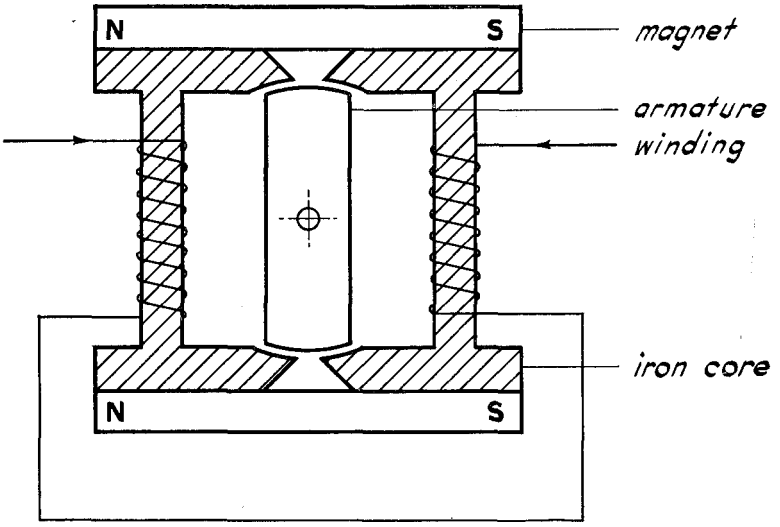


FIG. 6.6. Diagrammatic illustration showing principle of operation of a torque motor. Point of application of input signal is indicated by arrows.

FIG. 6.7. Instrument manufactured by Cambridge Instrument Co. Ltd., operated from dry batteries.

conceivable that other methods of recording may be developed in the future.

The moving coil galvanometer described on p. 52 is generally used to deflect the pen. More recently, a device known as a "torque motor" has been developed and this is sometimes used in place of the moving coil galvanometer. The following is a brief description of the principle upon which a torque motor operates.

A small moving iron armature, pivoted so that it can rotate, is situated in an iron core arrangement magnetised by permanent magnets. Many turns of wire are wound on the iron core and the output from the amplifier is fed into these windings. The resultant current has the effect of modifying the magnetic field, in which the armature is situated, so that it tends to weaken the field at one side of the core and strengthen the other. This unbalances the magnetic forces acting on the armature, causing it to rotate. Fig. 6.6 is a diagrammatic illustration of the arrangement. The recording pen is attached to the armature and, therefore, follows its movements.

The principal advantage offered by the torque motor is that it requires less power to operate and yet is highly efficient, which is due to the extremely small air gap that can be maintained between the armature

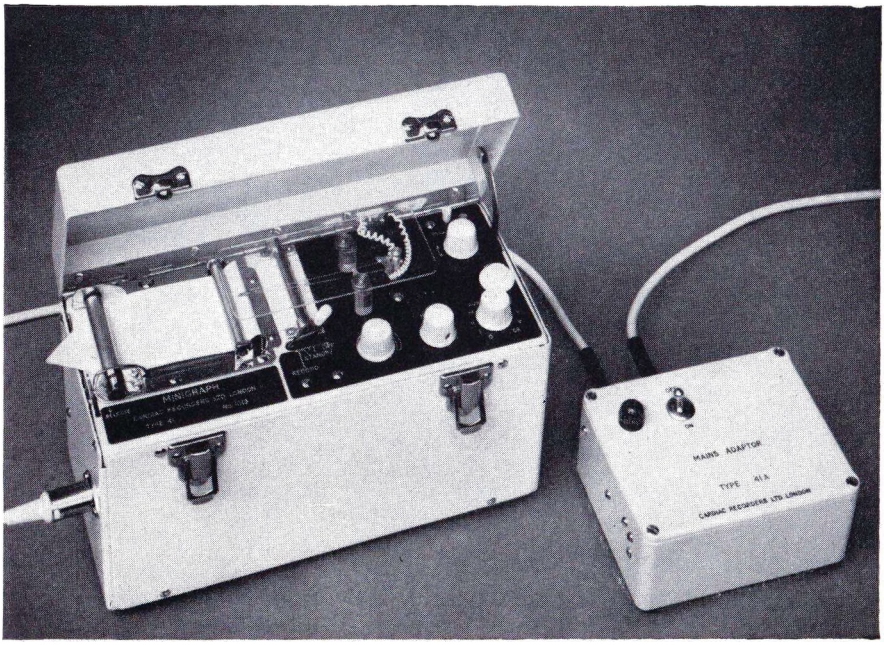


FIG. 6.8. Instrument manufactured by Cardiac Recorders Ltd., powered by rechargeable batteries.

and core. Furthermore, there are no control springs whose resistance has to be overcome, the necessary control being maintained by the magnetic field. In addition it is more robust than the moving coil galvanometer.

FIG. 6.9. Instrument manufactured by Sanborn (U.S.A.), operated from A.C. mains.

The Standardising and Control Panel

The control panel and methods for standardisation are generally similar to those employed in valve-operated instruments (see p. 54). It is possible to make battery-operated instruments with fewer controls; those commonly omitted are:

Control	Reason for Omission
Mains connection switch	No mains employed.
Fuse plate	No possibility of high currents flowing and, therefore, fuse protection is not required.
Earth connection terminal	Battery-operated instruments do not need to be connected to earth.
Interference eliminator	As indicated on p. 57 an injected A.C. signal is necessary to operate the eliminator and this is not available when an instrument is battery powered.

Figs. 6.7–6.9 illustrate some examples of modern transistor electrocardiographs.

RECOMMENDED BOOKS FOR FURTHER STUDY

Mullard (1961). *Reference Manual of Transistor Circuits*, 2nd ed. Wightman and Company Ltd., London.

Van Valkenburgh, Nooger and Neville, Inc. (1961). *Basic Electronics*, Part VI (of six parts), 2nd ed. The Technical Press, London.

CHAPTER 7

TO TAKE AN ELECTROCARDIOGRAM

IT is not proposed to give instructions how to operate any particular instrument, as these are provided by the manufacturers and vary for each type of outfit. The object of the remarks that follow is to comment on those aspects which are common to all apparatus, with special reference to the technician-patient relationship.

The crucial prerequisite for obtaining a good tracing is that the patient is physically and mentally relaxed, is comfortable, and does not move any part of his body. It is in order to achieve this aim that the technician's approach to the patient is of paramount importance.

To the technician, long association with his work will rob the taking of an ECG of any element of tension. It may well require a conscious effort on his part to be aware on each occasion that, to the patient, this procedure is likely to cause anxiety amounting, in some instances, to frank terror. Marked apprehension is particularly likely in patients who know that they have heart disease, and thus are heart-conscious, and also in those who suspect, perhaps wrongly, that they might be suffering from this condition. The fact that "electric wires" connect the body to the apparatus produces in some subjects the fear of "electric shocks". It is a most important aspect of the technician's work to create from the start an atmosphere of confidence, and to put the patient entirely at ease by reassuring him that he will not feel anything whatever from the intended investigation. Some simple explanation, like "measuring the amount of electricity in the body" or "taking something like a photo" is often helpful. If the patient is already familiar with the procedure from previous experience he will no longer be afraid, and any remaining apprehension will be far less marked. The technician may, therefore, find it helpful to enquire at the start whether the patient's ECG had been taken before.

Electrocardiograms should be taken with the patient supine, and a couch is therefore essential. This must be wide enough to ensure complete relaxation; the usual examination couch tends to be too narrow for this purpose. The recumbent position is far more relaxing than the sitting one. Moreover, in some patients, seemingly abnormal records are obtained in the sitting position, whereas those taken from the same patient supine are entirely normal. Such abnormalities consist in inversion of T waves in lead 2 and, rarely, in lead 1, which disappear immediately the patient lies down. They are most likely due to changes

in contact of the heart with neighbouring tissues resulting from the different positions of the body (Scherf and Boyd, 1953).

The technician should satisfy himself that ALL parts of the patient's body are supported by the couch and that no muscular effort, however small, is required to hold any part in position, since any muscular contraction is likely to produce interference by somatic muscle currents in the record. The patient's hands should not be clasped across the chest, but arms and hands should lie relaxed by his side on the couch, the legs slightly apart, and the heels not protruding beyond the couch. The patient should be instructed not to move any part of his body during the recording, e.g. head, fingers, etc. (see Fig. 7.1). A further source of interference is shivering of the patient. It is, therefore, essential to have the recording room comfortably warm, and the patient covered by a rug if necessary.

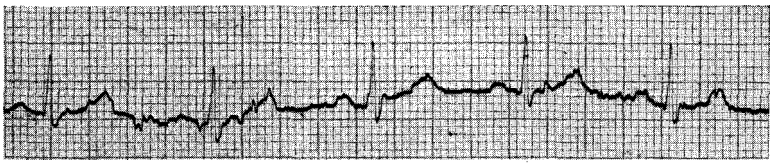


FIG. 7.1. Defect in record due to movement of arms or legs (lead II).

It is advisable to place the couch in such a way that the technician can keep the patient under observation and that the patient cannot see the apparatus during the recording. Relaxation is often made easier if the patient shuts his eyes while the tracing is taken, and conversation should, of course, be barred.

APPLICATION OF ELECTRODES

The use of direct contact electrodes, which is now universal, has been made practicable by the introduction of a form of lubricant jelly for preparing the skin surface. This has greatly simplified the taking of ECGs and made possible the present routine of recording multiple chest leads.

These metal electrodes are made of special alloy and only those provided by the makers of the electrocardiograph in use should be employed, otherwise undesirable electrical effects may ensue, for example, wandering of the base line.

The purpose of the jelly is to reduce the electrical resistance between the patient's skin and the metal electrode. The composition of the jelly is such that it is slightly abrasive, electrically conducting, and

sterile. When the skin is massaged with the jelly it removes part of its horny layer, which is the main site of the skin's electrical resistance, and also increases the blood supply to the massaged place; this results in an area of low electrical resistance.

Care should be taken to prepare the skin only over an area that will be covered by the electrode. The jelly should be applied with some pressure, the requisite amount of which varies with different subjects. In the average patient, massaging for about 5–10 seconds suffices; if the jelly is supplied in collapsible tubes, about $\frac{1}{2}$ inch of extruded jelly is adequate. Patients with hard, thick, hairy or oily skins are liable to have higher skin resistance, and greater pressure as well as longer application of the jelly is often necessary. The rubbing in of jelly is generally done with a piece of cotton wool, gauze, or a wooden spatula. Many workers prefer to use their fingers which makes it possible to gauge the pressure more accurately; this applies particularly to technicians who do not take large numbers of ECGs in succession. With this technique it is important for the technician to wash his hands with soap and water after application of the jelly and before recording, otherwise the equipment will be contaminated with jelly, resulting in corrosion of parts of the instrument. The base of the jelly is completely soluble in soap and water.

In some patients, for example, metal workers, the skin may be contaminated by minute particles of metal. Their removal before application of the electrodes is most important since they are liable to produce electrical side-effects. In such cases it may be necessary, before applying the jelly, to clean the skin with soap and water, or with alcohol. Preparation with the latter may also be advisable in patients with oil-contaminated skin.

In addition to preparation of the skin, a little jelly is also rubbed on the electrode before application, so that the skin-electrode surface remains moistened by the jelly and good conduction is ensured for the requisite period after application of the electrode. Recording should be started as soon as practicable after all electrodes are in place. If recording is delayed the jelly will dry, and the skin-electrode resistance will increase, resulting in distortion of the tracing; in this event the electrodes should be re-applied with fresh jelly. The screw on the electrode-terminal contact should be firmly tightened, otherwise artifacts due to bad contact and also A.C. interference are likely to occur.

Throughout the procedure it is essential to use clean electrodes and moist, uncontaminated jelly. After use the electrodes should be washed or scrubbed in warm water and soap, and the applied surface may, at intervals, be lightly rubbed with fine-grain sandpaper, or abraded with a little electrode jelly. Emery paper or metal polish should *never* be used. Care should be taken to keep the connecting terminals clean and

capable of making a firm screwed joint to the electrode leads connecting the instrument. The rubber bands for fixing the electrodes should also be washed in warm water and soap, and dried. They must never be wrapped around the electrodes for storage, as the sulphur in the rubber will attack and tarnish the electrode surface. If electrode jelly is allowed to dry on the rubber straps it will eventually damage the rubber, making it spongy and non-extensible. The jelly should be protected from air so that it keeps moist; containers must, therefore, be firmly closed. If the jelly is supplied in collapsible tubes, the nozzle of the tube should be wiped, otherwise a dry crust of salt crystals may form around the neck of the tube, which is liable to produce electrical side-effects.

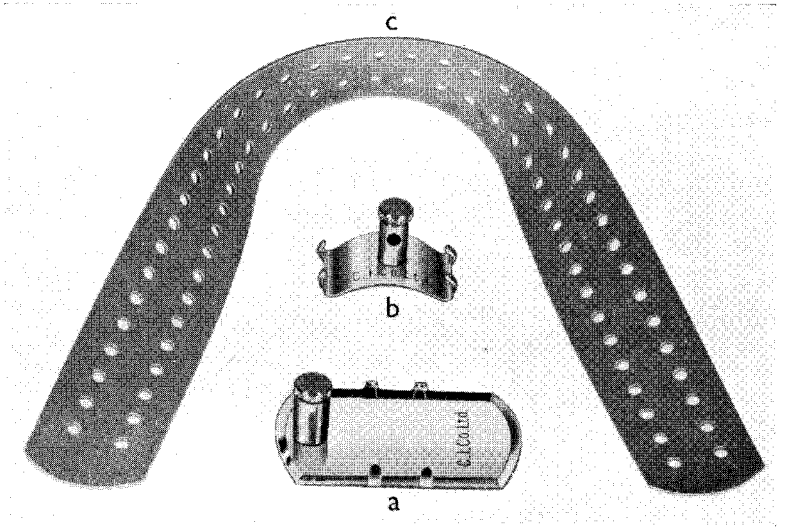


FIG. 7.2. Limb electrodes: (*a*) for use on adults, (*b*) for use on children, (*c*) rubber strap.

As far as the *limb* electrodes are concerned, the prepared area of the skin may be slightly larger than the electrode surface. The electrodes, measuring about 5 × 4 cm and carrying a connecting terminal, are applied to the inner forearms just above the wrist, and the outer left leg above the ankle, and held in position by rubber straps (see Figs. 7.2 and 7.3). In these positions the skin is usually soft and has less hair, but in many patients the inner surface of the leg is equally suitable. Usually a further electrode is applied to the right leg in the same way, which serves to eliminate or at least greatly to reduce certain common forms of extraneous A.C. interference. The actual position, on the limb, of the electrodes does not affect the ECG so that some latitude is

allowed to the technician. The rubber straps, which hold the electrodes in position, should be applied so as to exert a slight pressure. If they are tight, they impede the circulation, which militates against the desired reduction of skin resistance, also making the patient uncomfortable, which results in slight muscle movements, producing somatic muscle current interference. In patients with uncontrollable tremor the elec-

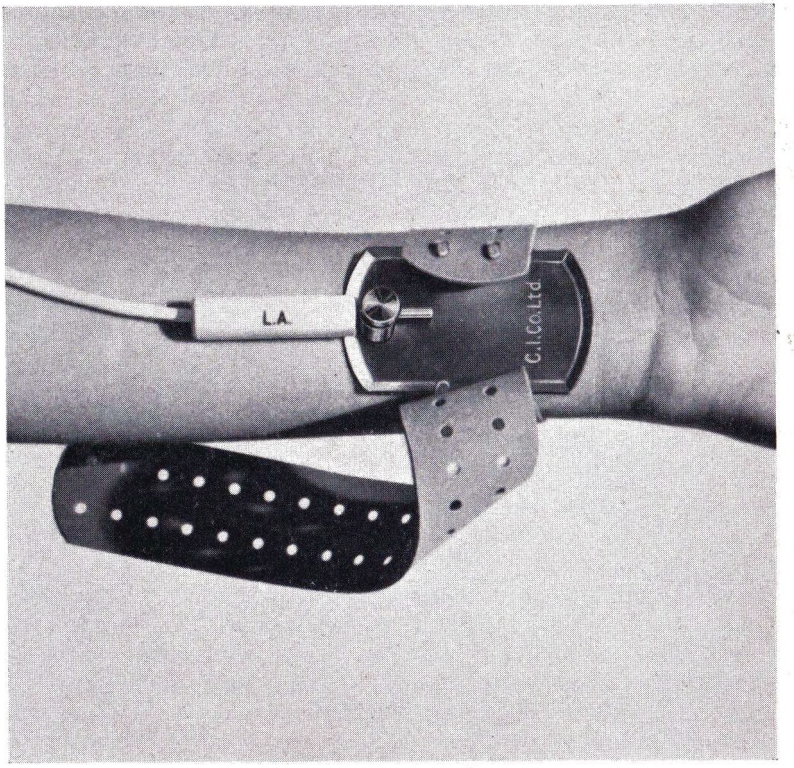


FIG. 7.3. Method of fixing limb electrode.

trodes are with advantage applied near the shoulders and to the upper thighs near the groins; with these positions, distortion of the ECG by somatic muscle currents is often greatly reduced and sometimes eliminated.

For infants and young children specially designed smaller electrodes of approximately half the size of those for adults are available (see Fig. 7.2*b*).

Care should always be taken to ensure that the patient lead does not run along the floor nor parallel to the mains lead or other active cable, such as that supplying a lamp. The mains lead should always be kept as remote from the patient as possible. The patient lead is best brought from the direction of the patient's head; it should be kept as straight as possible and the individual leads should run parallel with the limbs to which they are attached. The right leg (or unused limb) should be earthed to the instrument; modern patient leads make provision for this.

Great care must also be taken to ensure that each electrode is attached to the correct lead-wire connecting the instrument. With some wrong connections, tracings are obtained which simulate those encountered in certain abnormal heart conditions.

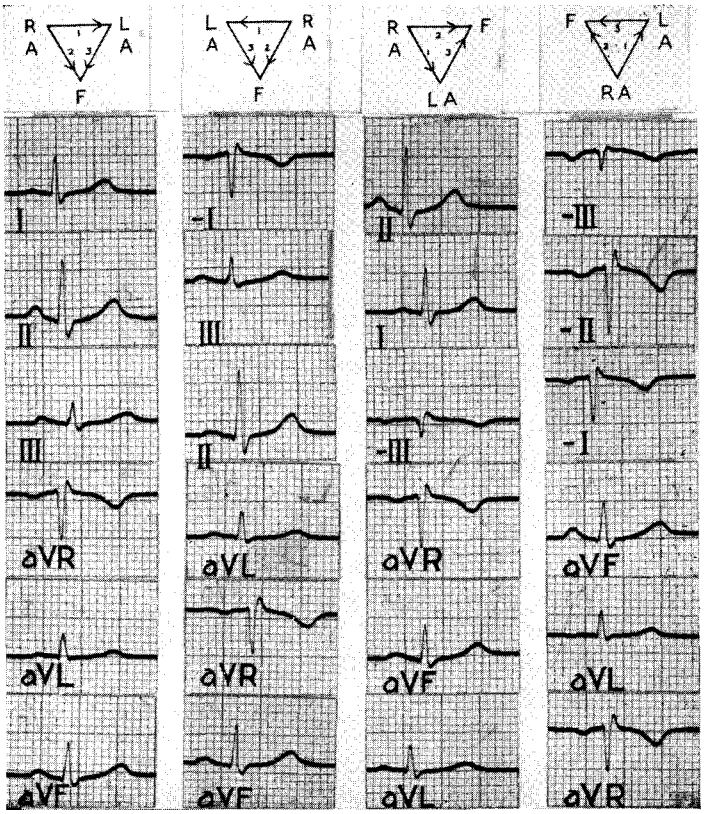
For instance, should the right arm electrode be inadvertently connected to the left arm and *vice versa* (see Fig. 7.4*b*), the result would be: all waves in lead I would be reversed in direction; lead II, as recorded, would in fact be lead III; and lead III, as recorded, would be lead II. In the unipolar limb leads, aVR, as recorded, would be the true aVL, and *vice versa*. Unless the technical error is suspected, such a tracing may give rise to the erroneous diagnosis of a congenital abnormality of the heart (dextrocardia) in which records of such appearances are recorded with correct technique.

The inadvertent reversal of the left arm-left leg connections (see Fig. 7.4*c*) is far more difficult to detect, even if unipolar limb leads are included. In this event, lead I, as recorded, is the true lead II; and "lead II" the true lead I; in the recorded lead III all deflections are reversed in direction. Tracings of this appearance, taken with correct technique, are found in subjects with a transverse position of the heart. Ashman and Hull (1945) have pointed out that the error may "be suspected when there is a prominent P wave in lead I, together with a very small R, or an apparently deep Q followed by an R and no S, and inverted P waves in lead III". In practice, this error is rarely suspected, but, if it is, the tracing should, of course, be retaken.

If, on the other hand, the right arm-left leg connections are reversed (see Fig. 7.4*d*), all bipolar leads appear as mirror images of normal lead tracings and it is seen at a glance that the recording must be at fault. The recorded lead I is the mirror image of the true lead III, "lead II" is the true lead II with all deflections reversed, and "lead III" the mirror image of the true lead I. The features of the reversed leads aVR and aVF also reveal an obvious mistake in connections.

Regarding *chest leads*, it is most important that the area over which the skin is prepared is not larger than that covered by the chest electrode. Even a small difference in the site of placement of the chest electrode results in a noticeable difference in the ECG. Furthermore, the points from which the chest leads are recorded are quite near to

each other and, since the jelly is an electrically conducting substance, any jelly between points on the patient's chest will provide an electrically conducting pathway between these points. This results in a tracing which registers potentials from the wider area covered by the



a *b* *c* *d*

FIG. 7.4. Effect of reversal of electrode connections: (*a*) correctly recorded, (*b*) reversal of left-arm and right-arm connections, (*c*) reversal of left-arm and left-leg connections, (*d*) reversal of right-arm and left-leg connections.

jelly and makes it impossible to obtain accurate records. Compared with accurate tracings from the individual points, such records may be, and often are, distorted to such an extent as to be misleading. **Any jelly bridge between recording points on the chest must therefore be strictly avoided.**

When recording chest leads the jelly must be rubbed in with adequate

pressure also on the areas under the limb electrodes. Failing this, the resistance in the three branches making up the indifferent electrode, for example, Wilson's Central Terminal (see p. 23), may vary so much that the central terminal is no longer at (practically) zero potential. Instead, it may show variations in potential with the heart's action due to those

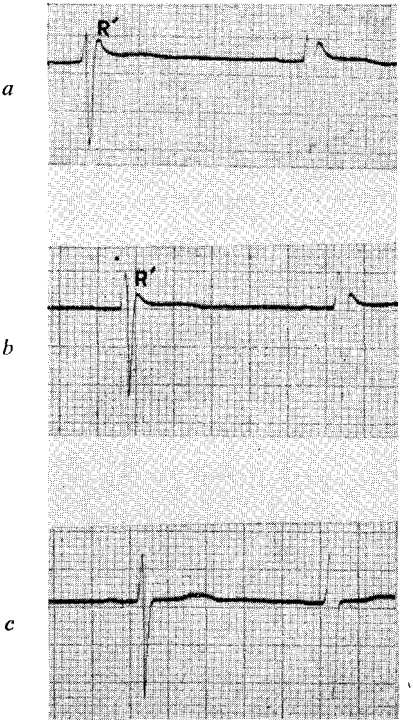


FIG. 7.5. Distortion of a chest lead (V_2) by inadequate application of electrode jelly. (*a*) Gross distortion; note in particular the second upstroke marked R'. (*b*) After rubbing in more jelly: distortion less marked. (*c*) After rubbing in still more jelly: normal record. R' waves no longer present. Apparent former abnormalities shown to have been artefacts. (S waves of first complex of each strip touched up for reproduction.)

predominating in the limb with the lowest skin-electrode resistance. If one or two of the limb electrodes are badly applied and there is thus a very high skin-electrode resistance in these branches of the central terminal, the incorporated 5,000 ohm resistances are no longer effective. This results in a serious distortion of the chest lead record.

Faultless application of the exploring chest electrode is particularly

imperative when recording leads V–1, V–2 and V–3. If over these sites the jelly is applied in inadequate quantity or with insufficient pressure or for too short a time, the skin-electrode resistance will be too high. The resulting record might then simulate abnormal records otherwise found in certain types of heart disease, whereas accurate records of these leads may be entirely normal (Fig. 7.5). This was first pointed out in 1956 by Gentile, who also gave the mathematical reason underlying this phenomenon.

Different types of chest electrodes are available. All are smaller than the limb electrodes, being circular and approximately 2 cm in diameter. Most are self-retaining by suction, which draws up the skin to make firm contact with the metal electrode. Suction electrodes are easy to apply, usually do not slip with respiratory movements, and have largely replaced those strapped around the chest or held in position by

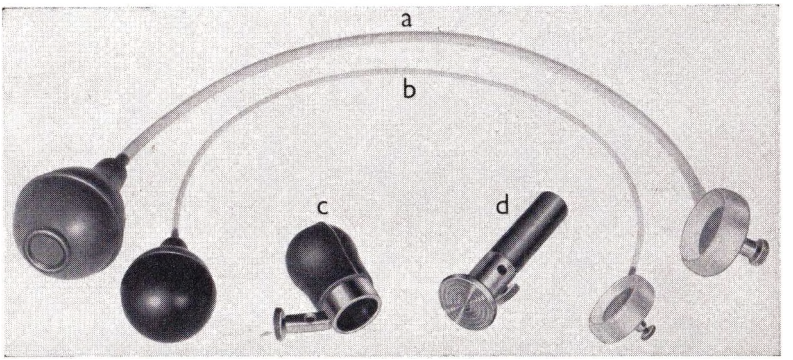


FIG. 7.6. Examples of chest electrodes: (*a*) Burger suction electrode for adults, (*b*) the same for children, (*c*) suction electrode, different pattern, (*d*) "hold-on" electrode.

adhesive tape. In patients with protruding ribs and very hairy chests suction electrodes are unsatisfactory, because the irregular contact surface prevents the suction from being maintained for the requisite time. In such cases it may be necessary to use a type of electrode which can be manually held in position by the technician, by means of an insulating handle attached to it. Fig. 7.6 shows different types of chest electrodes.

More recently, wet-pad electrodes have been marketed, their application requiring only moistening with tap water. There seems to be some doubt on theoretical grounds about the accuracy of records obtained with these electrodes. More experience is necessary to establish their

reliability or otherwise, when used with cardiographs of various designs.

Special electrodes are available for passing down the œsophagus, which are a miniature form of suction electrode (Fig. 7.7). Œsophageal electrodes should only be used by special instruction of the physician and under his supervision. The same applies to electrodes employed in conjunction with cardiac catheterisation for the recording of intracardiac cardiograms.

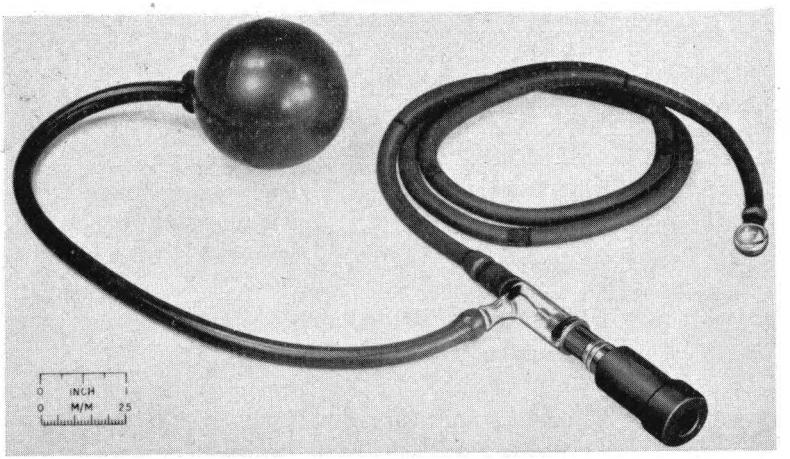


FIG. 7.7. Œsophageal electrode.

RECORDING PROCEDURE

Direct writing instruments, whether valve or transistor operated, require a short period, usually at least 3 minutes, to stabilise after switching on. It therefore saves time to switch on the instrument before applying the electrodes to the patient; the instrument will then be ready for recording when the electrodes are in place.

The following routine recording procedure is recommended:

(i) Switch on instrument.
(ii) Apply electrodes.
(iii) Ensure that the patient is comfortable and completely relaxed.
(iv) Standardise the instrument, i.e. adjust its sensitivity to give a deflection of 10 mm for 1 millivolt.
(v) Recheck that patient is completely relaxed.
(vi) Start recording.

At the beginning, record standardisation deflection. (With string

cardiographs standardisation deflections should be recorded with each lead. This is not necessary with direct writing instruments.)

The usual twelve-lead cardiogram is then taken in the following way:

STANDARD (BIPOLAR) LIMB LEADS

Lead position indicated on switch	*Description*	*Switch connections*
I	Lead I	Right arm-left arm
II	Lead II	Right arm-left leg
III	Lead III	Left arm-left leg
	AUGMENTED UNIPOLAR LIMB LEADS (Goldberger Central Terminal)	
aVr	Augmented unipolar right arm lead	Right arm-(left arm + left leg)
aVl	Augmented unipolar left arm lead	Left arm-(right arm + left leg)
aVf	Augmented unipolar left leg lead	Left leg-(right arm + left arm)
	UNIPOLAR CHEST LEADS (Wilson's Central Terminal)	
V	1–6 according to the location on the chest of the exploring chest electrode	Chest—Wilson's Central Terminal

See Figs. 7.8–7.10.

For additional chest leads, see p. 26.

If it is necessary to record certain leads with half-sensitivity, the appropriate standardisation deflection should also be recorded.

On comparatively rare occasions special leads may be requested for which no provision is made on the selector switch. These can usually

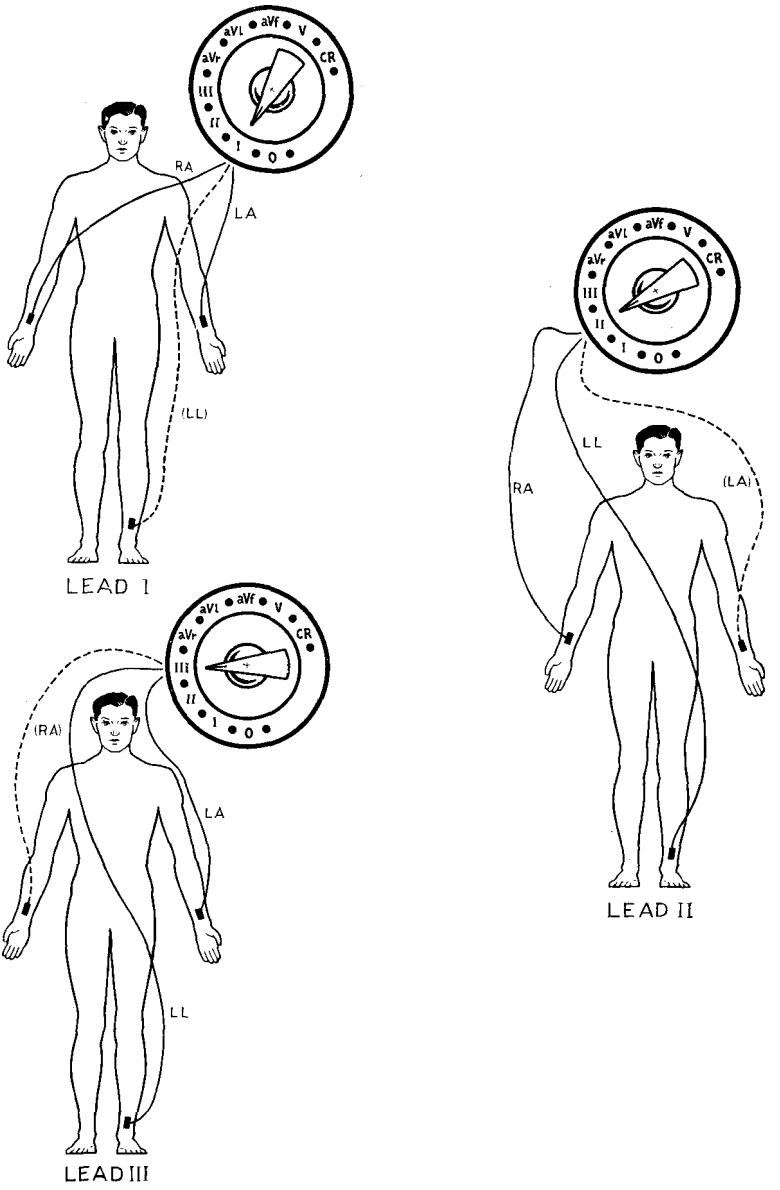


FIG. 7.8. Diagrams illustrating the connections, and positions of lead selector switch, for the three standard bipolar limb leads. Broken lines indicate the connection not used in the particular lead.

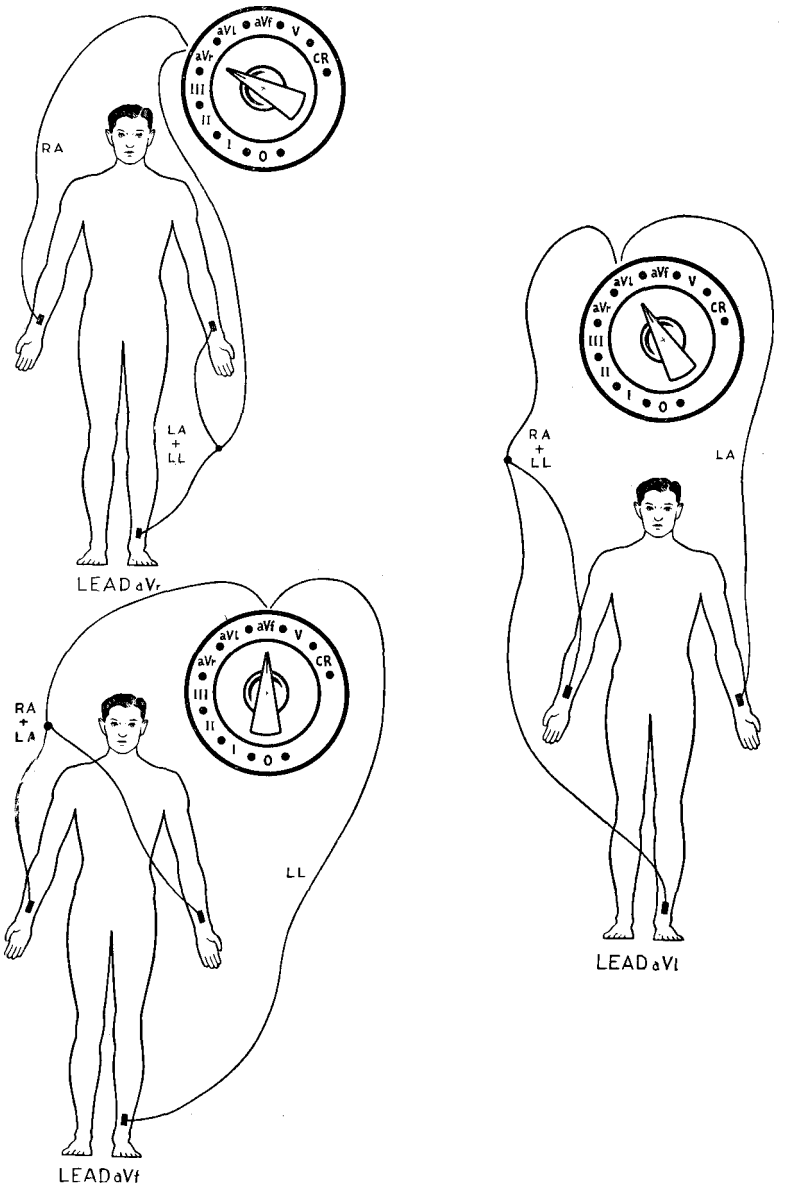


FIG. 7.9. Diagrams illustrating the connections, and positions of lead selector switch, for the three augmented unipolar limb leads.

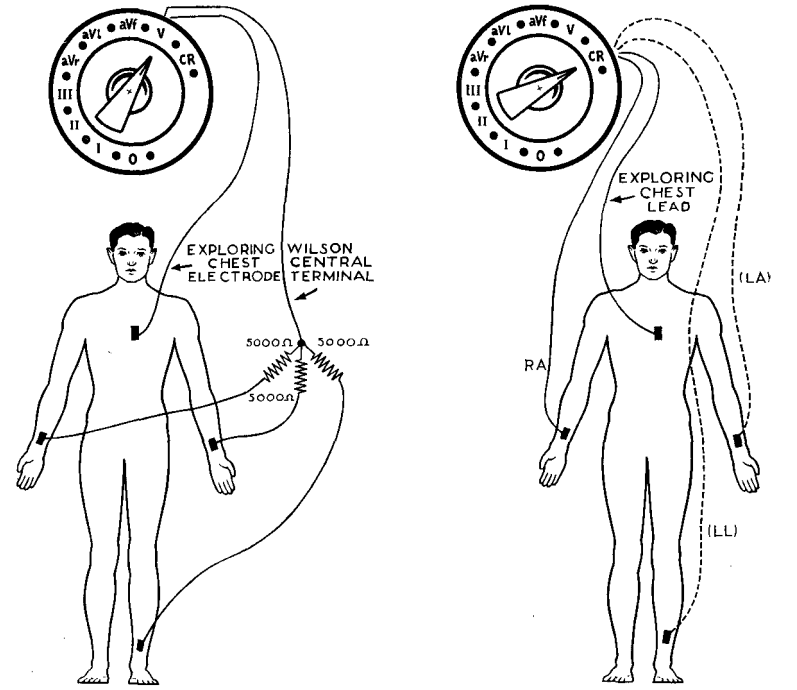


FIG. 7.10. Diagrams illustrating the connections, and positions of lead selector switch, for V and CR chest leads. Broken lines indicate connections not used.

be recorded without difficulty with the selector switch in the position V, or in one of the bipolar limb lead positions, depending on whether a unipolar or bipolar lead is required.

REFERENCES

Ashman, R., and Hull, E. (1945). *Essentials of Electrocardiography*, 2nd ed. Macmillan, New York, p. 10.

Gentile, C. (1956). "Electrocardiogram's distortions due to a high skin-electrode resistance. A simple clinical method for measuring this resistance." *Amer. Heart J.*, **51**, 906.

Scherf, D., and Boyd, L. J. (1953). *Clinical Electrocardiography*, 4th ed. Heinemann, London, p. 140.

CHAPTER 8

EXTRANEOUS INTERFERENCE AND COMMON FAULTS AND THEIR ELIMINATION

ELECTROCARDIOGRAMS taken on any type of electrocardiograph may be marred by a number of extraneous conditions, those most commonly occurring being:

(*a*) Alternating current interference;
(*b*) Somatic tremor;
(*c*) Disturbances due to respiration;
(*d*) Broken lead connections.

These conditions are described in some detail below, together with suggestions for their prevention or elimination.

Alternating Current Interference

This is frequently due to the presence of a nearby cable carrying an alternating current supply. It can be recognised as a constant baseline ripple, with constant frequency and amplitude. Usually the interference takes one of two forms, namely, electrostatic or electromagnetic.

ELECTROSTATIC INTERFERENCE is due to the fact that a charged conductor (e.g. a mains cable) will cause a charge of opposite polarity to be induced in a nearby conductor. For example, if a wire carrying an electric current assumes a certain polarity, let us say positive, it will cause a wire situated nearby to assume a negative polarity. If the original wire is carrying alternating current then its polarity will change at the frequency of the supply, e.g. 50 cycles per second. The polarity of the nearby wire will also change at the same frequency, and interference may be caused with any current previously present in it.

Electrostatic interference is minimised in an electrocardiograph by careful screening of the amplifier circuit and the patient lead.

ELECTROMAGNETIC INTERFERENCE is set up in a different way. When an electric current flows in a wire, a magnetic field is set up around the wire and, if the direction or magnitude of the current is changed, the varying magnetic field causes a voltage to be induced in any wire situated in this field. If an alternating current is flowing in the wire, waves of interference are radiated in much the same manner as radio waves are sent out from a transmitting station. The patient lead, or

even the patient can be considered as the receiving aerial feeding unwanted interference signals into the amplifier of the cardiograph.

Whilst interference is often due to ordinary house or hospital wiring, it can arise from other sources, including household electrical appliances such as electric fires or electric blankets. These generally give rise to a ripple on the record which has the same frequency as that of the electric supply (Fig. 8.1). In Great Britain this is 50 cycles per second, and in the U.S.A. usually 60 cycles per second. Interference ripple can also be set up at frequencies other than those of the A.C. mains supply, e.g. by diathermy or other short-wave apparatus. It is not uncommon to pick up a ripple having a frequency of 100 cycles

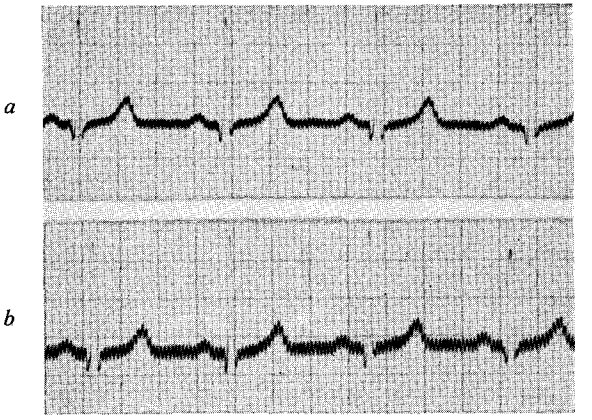


FIG. 8.1. Alternating current interference (*a*) moderate, (*b*) marked degree (lead II).

per second, which can readily be recognised as A.C. interference, the waves being regular and of constant amplitude. Lifts, X-ray or dental equipment are often causes of difficulty in hospitals. Such sources can be suspected by the intermittent nature of the interference. Sometimes, especially during domiciliary visits, trouble may be caused by sources outside the home, e.g. trolleybus wires, electric trains, etc., but fortunately such occurrences are rare.

If, with the instrument in the same location and all conditions seemingly normal, there is a sudden persistent interference, this can often be traced to a disconnected or broken earth wire. Other causes include a defect in the patient lead, which is usually due to the screening of the lead having come into contact with the centre core and the screen-

ing thus becoming ineffective; or a defect in the electrocardiograph itself.

Elimination

First ensure that the interference is not due to a simple fault in general application. Check that all terminals are tight; that the electrodes are properly applied; and that the earth wire (if a separate one is in use) is not broken, which usually occurs at or near its terminals. It is a good plan at this stage to ascertain that the interference is not due to some defect in the instrument. To test this, switch the patient lead selector to the "0" position and run a length of record: if no ripples appear then it is certain that the cause is external to the input circuit of the instrument. If, on the other hand, a ripple appears on the baseline, it is an instrumental fault that may be difficult to trace; in such cases the manufacturers of the apparatus should be consulted.

Assuming that the interference is external, it is advisable to locate its source. In the first place, disconnect or, if this is not possible, switch off all electrical appliances in the room, such as lights near the patient's bed, electric blankets, fires, etc., also, if necessary, more distant electrical equipment, e.g. vacuum cleaners, refrigerators, washing machines. If the interference still persists, it is often helpful to pull the bed away from the wall; if necessary and space permitting turn it through an angle of 90°. Lastly, connecting the metal frame of the bed to a nearby cold water tap by a wire may cure the trouble.

There is no hard and fast rule that can be applied for the elimination of A.C. interference. An expedient that is entirely effective in one location may be useless in another; but once the successful corrective is established, no further difficulty, other than intermittent faults, should ensue, providing the instrument has not developed a defect, and is used in the same location and under the same conditions.

On most mains-operated instruments an interference eliminator is fitted, see p. 57. Where all other measures fail, this may be used as a last resort, but it is essential on principle first to try and locate and eradicate the interference. Using a suppressor is never more than a second best; furthermore, it often has to be readjusted for each lead separately and is also very wasteful in the consumption of paper.

A small ripple of interference of (say) 0·5 mm is enough to spoil a record, and nothing but entire eradication should be aimed at.

The ripple may at times be so great that the recording pen oscillates wildly and bangs against its stops. Under these conditions the selector switch should be turned to the "0" or "off" position to avoid seriously damaging the pen or pen mounting. The reason for such gross interference can usually be seen without difficulty, e.g. an electrode falling off, or a lead terminal having pulled out from the electrode connecting post.

Somatic Tremor

This disturbance is caused by small currents generated in skeletal muscles. It resembles the type of A.C. interference described above in that it is a series of waves superimposed on the cardiogram. It differs by the waves having variable amplitude and variable frequency (30–70 cycles per second), and it is this variability which permits somatic

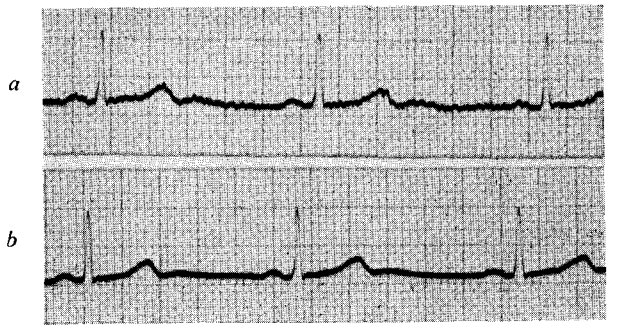


FIG. 8.2. (*a*) Somatic interference due to inadequate relaxation, (*b*) undistorted record after adequate relaxation (lead II).

tremor to be identified and distinguished from A.C. interference (Fig. 8.2). Sometimes alternating current and some somatic interference may occur simultaneously, which become additive at points where deflections coincide, and a considerable irregular "saw tooth" effect is created on the record. The appearance may resemble alternating

FIG. 8.3. Alternating current with super-imposed somatic interference (lead II).

current interference and often is treated as such, the somatic component being missed (Fig. 8.3). If the effect varies in frequency and in amplitude it may safely be assumed that some of it is due to somatic activity. Somatic interference currents may cause vibrations of the galvanometer of up to 2 mm; if the amplitude exceeds 2 mm, the trouble is almost certainly due to alternating current interference.

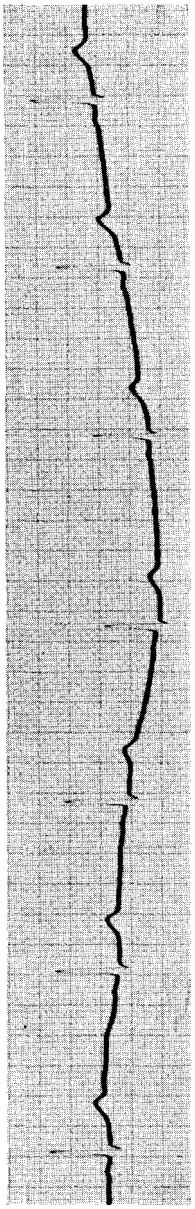


FIG. 8.4. Wandering of baseline due to respiration (lead V4).

Elimination

The technician's right approach to, and preparation of, the patient are the points of crucial importance; they are fully described on pp. 76 *seq.* For recording from patients with uncontrollable tremor, see p. 80.

Disturbances Due to Respiration

These are caused by respiratory changes in the position of the heart, in turn due to the movements of the diaphragm (see also Chapter on Biological Aspects, p. 39). The effect is a wandering of the baseline of the tracing with inspiration and expiration (Fig. 8.4), being more marked on deep breathing, also changes in the amplitudes and sometimes direction of individual waves in certain leads. This tends to make interpretation more difficult and less reliable.

Elimination

It is often possible to eliminate, or reduce to a negligible extent, this disturbance by asking the patient to take shallow breaths. Failing this, it may be desirable to re-take the cardiogram with the patient holding his breath. Generally, this should not produce any discomfort as each lead does not usually take more than about 6 seconds.

Broken Lead Connections

Sometimes the recording system appears to be "dead" on two of the three standard bipolar limb leads, whereas the remaining one can be recorded normally. This is rarely due to a defective selector switch, which is often wrongly suspected, but nearly always to a break in one of the wires in the patient lead. These are of light weight, being flexible where the cable is joined to the terminal, and since they receive considerable bending in use they may fracture from time to time. Such a break may also occur where the individual lead leaves the main cable. It is not always easy to recognise this, since the wire breaks inside the rubber or plastic covering and thus appears to be sound; indeed, the ends of the broken wire may, for a time, be held together sufficiently to produce records,

although the effect of this kind of breakage is likely to be intermittent and to raise suspicion of a technical fault. It is easy to locate the defective cable by noting which one of the three leads can be recorded. If leads I and II are "dead", the broken cable will be the right-arm connection; if leads II and III, the left-leg connection; and if leads I and III, the left-arm connection. This will easily be understood, since in each case the broken connection is the one which is common to the two dead leads.

Elimination

It is possible for the hospital electrician to repair the patient lead, but great care should be taken to avoid soldering the screening to the central lead wire. It is general practice in electrical engineering to "bond" the screening to earth (this is, in fact, done on the instrument end of the cable) and, unless an explanation is given to the electrician, it is almost certain that the central core and screening will be soldered together. The effect will be to give rise to alternating current interference (as mentioned above).

Some maintenance and servicing instructions are usually incorporated in the operating instructions supplied with the instrument and these may be consulted for faults of a simple nature. Modern electrocardiographs are complex instruments and apart from repairing a broken earth lead or patient lead, or possibly replacing a valve by an identical one (see p. 51), it is advisable to request the makers to service the instrument.

CHAPTER 9

MOUNTING ELECTROCARDIOGRAMS

BEFORE electrocardiograms are sent to the requesting department in a hospital, or filed as reference records in the cardiographic department or with a cardiologist's private notes, they are usually mounted on cardboard (for exceptions, see p. 99). The way in which this is done is largely a matter of personal preference and only a few general remarks seem appropriate.

As far as 12-lead cardiograms are concerned, which are now routinely taken, in cases with normal rhythm three cycles of each lead are usually sufficient. The cutting of the records into strips of the requisite length by a guillotine cutter saves time, though some technicians prefer scissors. Many technicians adopt some kind of standardised marking of the individual leads, which is useful for preventing mistakes in mounting, such as wrong designation of leads, mounting a lead upside down, etc. If leads are marked in pencil on the back of the records, care should be taken to use little pressure, otherwise lines can easily show through, thus spoiling the tracing and making it unsuitable for later reproduction. The value of Einthoven's law for the recognition and prevention of mistakes in mounting is discussed on pp. 26–33.

Stapling is not advised, as this method hardly ever fixes the records flat on the cardboard, and tracings are likely to become damaged and detached in the course of time and by handling. Glueing or pasting the strips on to the cardboard is a simple and quick method, but has the disadvantage of being messy. In practice, it is almost unavoidable that traces of the liquid adhesive spread to the face of the record, disfiguring it, or protrude beyond the strips of the mounted record in certain places where it then tends to stick to other records, paper, etc. Double coated tape, $\frac{3}{8}$ inch or $\frac{1}{2}$ inch wide, is another easy and quick method. One or two strips of such tape are fixed vertically on to the cardboard, the protecting layer is then removed thus exposing the other adhesive surface, and the strips of the individual leads are pressed on to the tape, which makes the strips firmly adhere. This method has the advantage of being cleaner than glueing. A more elaborate method of mounting by heat, using a thermostatically controlled electric iron and mounting tissue specially prepared for this procedure, which can be combined with protection of the record by plastic tissue, is also em-

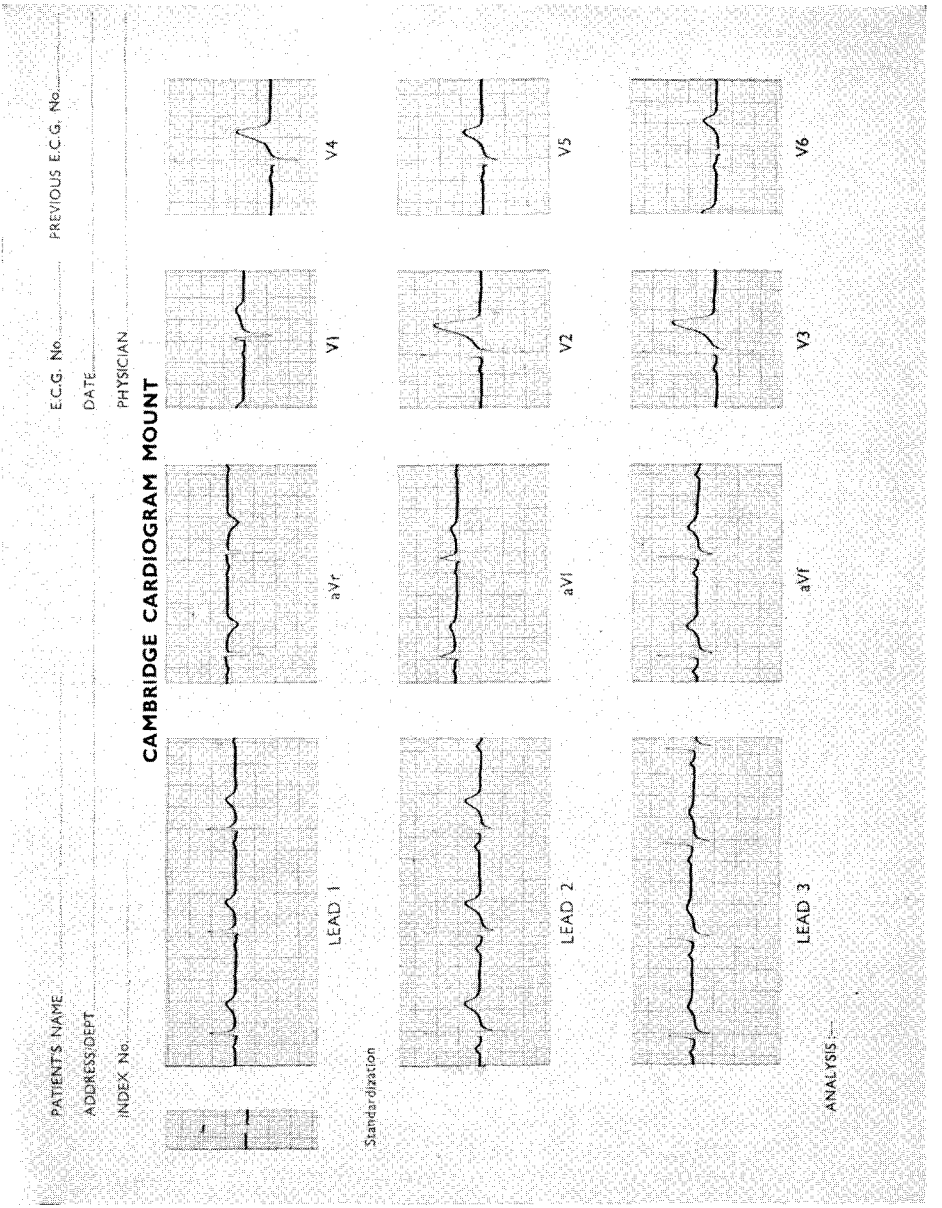


FIG. 9.1. Example of mounting card used for 12-lead records.

ployed. This is claimed to ensure more permanent records, capable of better resisting damage by water or heat.

The choice of the size of cardboard is largely a matter of personal preference and often depends on the size of the patients' notes used by the individual hospital or cardiologist. It determines the number of leads which can be fixed on any one sheet, usually six or twelve, in some instances even more if additional leads were taken. The use of both sides of the cardboard sheet is not advised.

An alternative method is to mount shorter lengths of the records on a double special card 11 by $8\frac{1}{2}$ inches. In such cards, windows are cut in a particular pattern (see Fig. 9.1). In this case, leads I, II and III cover three complete cycles on an average, the unipolar limb leads two and the six precordial leads one complete cycle each. The records are fixed behind the windows by strips of gummed surface. Great care must be taken to ensure that the correct portion is fitted into the appropriate window. In the United States, cards of similar size are used. Appropriate portions of the individual leads are inserted, either into cellophane pockets, or behind cut-out windows by means of a special manipulator. These ways of mounting produce æsthetically satisfying results, but are expensive and the finished products require considerable storage space.

CHAPTER 10

INDEXING AND FILING OF ELECTRO-CARDIOGRAMS AND REPORTS

INDEXING and filing of records and reports is another aspect of a technician's work which is largely a matter of personal preference, and depends so much on circumstances, that it would be presumptuous to recommend any particular procedure. It seems fully justified, however, on the grounds of extended experience to make some suggestions, which are intended to serve as a basis for devising a system which will fit individual requirements.

Records should be consecutively numbered as soon as they are taken. It is essential that a mounted reference record, consisting of a portion of each lead, is available in the cardiographic department. These are preferably filed in numerical order. If cardiograms are taken on films, the same suggestion applies to their filing. Where several records are taken of the same patient it is an advantage to file all his reference records together with the most recent tracing of the case.

A certain number of records should be filed and stored uncut, for example, tracings of complicated arrhythmias, serial electrocardiograms after exercise, some multichannel records, where interfering with the continuity of the tracing would destroy important information which is necessary for interpretation and analysis. There is no satisfactory method other than rolling such records and marking them with the patient's name, date, reference number, etc. The most suitable way of storing the rolls depends on the space and facilities available. In the great majority of hospitals the number of records required to be filed uncut is very small compared with the total, and this applies even more to records in private practice.

As a rule, at least three separate indices or files are desirable in a cardiographic department of a hospital and a fourth can, with advantage, be added. These, being additional to the patient's general hospital case notes, are:

1. Name card index.
2. Date index.
3. File containing the physician's reports.
4. Classification card index.

Indices 1 and 4 are preferably kept as card indices, whereas index 2 may be an entry book.

Date Index

Taking for convenience the date index first, this is usually in the form of a book, which may be divided into the following columns:

Date	Prefix of hospital (in case of the cardiographic department serving several hospitals)	Number	Name of patient	O.P. or I.P.	New or old patient (or: date and/or number of previous records, if any)

A date book kept in this or a similar fashion gives an indication of the daily work of the department, and the weekly, monthly or annual figures can easily be ascertained. It also makes it easy to keep a check on the use of materials and to establish the intervals at, and the quantities in which, materials should be ordered. The number of patients sent for examination by the various members of the medical staff and the different departments can also be found in a short time and with little trouble.

Name Card Index

This should contain the patient's full name and address, the serial number(s) of the electrocardiogram(s), and, as far as practicable, the hospital index or unit number of the patient's case notes; the last affords a cross reference between it and the serial number(s) of the electrocardiogram(s). The name card index makes it possible for the technician to look up at a glance the patient's previous records, which should always be submitted with the new record to the physician in charge, for the purpose of comparison when reporting. The cards are filed alphabetically and should contain the following data:

Surname.
Christian name(s).
Address.
Electrocardiogram(s) No(s).
Index (Unit) No.

File Containing the Physician's Reports

In some hospitals the report of the physician in charge is sent with the tracing to the member of the staff who requested the investigation. It is a great advantage to have a copy of reports available in the cardiographic department. This can be done with a minimum of trouble by having the reports typed with a carbon copy on the back of the request form. If the request forms, which also contain the number of the record, are filed in numerical order according to the serial number of the records, a copy of the physician's report will automatically be available

REQUEST FOR ELECTROCARDIOGRAM

E.C. No..... Previous E.C. No..... Dept..... Unit No.....

Name..... Age..... Consultant.....

Address .....

Clinical Diagnosis .....

History.....

Clinical Features.....

.....

.....

Patient's Build: Average..... Obese..... Asthenic.....

Has digitalis been taken within the last fortnight? .....

Radiological / Clinical } Evidence of Cardiac { Dilatation? ..... Blood Pressure / Hypertrophy?.....

Any other drugs taken within the last fortnight? .....

.....

Recorded by: Date .....

..... HOSPITAL. Signed.....

.....

Ecg. Physician I/C Cardiol. Dept. Date.....

.....

HOSPITAL. Unit No.....

REPORT ON ELECTROCARDIOGRAM

E.C. No..... Previous E.C. No..... Date of E.C.....

Name..... Age..... Dept..... Consultant.....

FIG. 10.1. One variety of a request/report form for electrocardiographic examination. The lower half appears upside-down, the reason being that, when the form is folded at its perforation in the middle (indicated by the dotted line), the carbon copy of the report appears the correct way up on the back of the request form.

in the department. Much time may thereby be saved to a physician who, reporting on large numbers of cardiograms, often has to compare two or more records of the same patient.

Fig. 10.1 reproduces a request-report form which has been found very satisfactory over a long time in a group of hospitals. It consists of two halves with a perforation across the middle. The upper half is the request section, which is completed by the requesting member of the medical staff; it contains provisions for entering a minimum of clinical data which are indispensable for the interpretation of the record. The lower half is the report section, which is detached after the physician has completed his report. The latter includes provision for entering the date of the tracing and the date on which the report is made; this is considered important because in certain circumstances changes in the patient's condition, occurring between these dates, may be of great clinical importance.

Classification Card Index

The object of this is to group the cases according to the electrocardiographic findings. The headings of the groups should be decided by the physician in charge. Such an index is a great convenience in several respects, for example: to extract records showing a particular condition which may be required for teaching or publication; for statistical purposes; for analyses or surveys of the incidence of conditions according to age groups or sex, or over longer periods of time, etc. Such an index is fitted with guide cards, indicating the various groups with their headings in alphabetical order. The cards should contain the following data:

Group.
Surname.
Christian Name(s).
(Age).
(Sex).
Electrocardiogram(s) No(s).

The function of the technician in this branch of his work is: to enter the patient's name and particulars in the date book when the record is taken; to fill in the name card and file it in the name card index, making sure that the numbers of *all* the records are entered on the card in instances where several records are taken of the same patient. The technician is not required to make any report. When this has been done by the physician in charge, the form is returned to the technician, who should then make the entry on the classification card and file it in the appropriate index; separate the two halves of the request-report form; send the report section with the record to the requesting department and, finally, file the request section in numerical order. By filing in

this way the request sections, which have a carbon copy of the report on the back, all relevant clinical and electrocardiographic data are available in the cardiographic department and can be turned up at a moment's notice.

As stated at the beginning of this chapter, this is not intended to offer more than some suggestions, based on a system which has proved satisfactory. Conditions in different cardiographic departments vary so widely that modifications and variations may well be necessary or desirable to suit individual requirements.

CHAPTER 11

PHONOCARDIOGRAPHY*

As cardiographic technicians are sometimes asked to take, or assist in the taking of, phonocardiograms, a discussion of some fundamental aspects of this method of investigation is appropriate.

General Considerations

Phonocardiography is the graphic registration of heart sounds and murmurs. Its principle consists in converting the acoustic phenomena associated with the heart's action into electrical impulses, which are amplified and recorded by a galvanometer in a way similar to electrocardiograms. The conversion is effected by a suitable microphone placed on the chest.

Medically, heart sounds are a normal phenomenon and distinguished from murmurs, which are mainly abnormal. The murmurs occur during the normally silent intervals between the heart sounds and most of them have a longer duration than the sounds. From the point of view of physics, both are classified as sounds, that is, fluctuating pressure waves of air.

If a phonocardiogram is to be useful to the clinician it must reproduce what he hears when listening with a stethoscope to a patient's chest; otherwise he cannot interpret it in terms that have a medical meaning. Therefore, in the design of phonocardiographs, the characteristics of human hearing, and also the changes in the sounds brought about by the stethoscope, have to be considered.

Importance of Characteristics of Human Hearing for Phonocardiography

One of the salient points is that the ear is relatively insensitive to low-pitched sounds—that is, to those of low frequencies, ranging from about 20 to 60 cycles per second (c.p.s.)—and far more sensitive to high-pitched ones, particularly to those around 2,000 c.p.s. For example, a sound to be just audible at 20 c.p.s. would have to be about a thousand million times more intense than at 2,000 c.p.s.

Applying this general principle specifically to phonocardiography: Normal heart sounds have much lower frequencies but much higher actual intensities than abnormal heart murmurs. However, owing to the relative insensitivity of the human ear to low frequencies, the low-

* This chapter may be omitted, particularly at the first reading, by those not especially interested in the subject.

pitched heart sounds are, despite their greater intensity, heard relatively faint, compared with the higher-pitched but far less intense murmurs. The properties of the stethoscope aggravates this, because it attenuates the low-pitched sounds. Therefore, if the sounds were recorded as they exist on the chest wall, unmodified, the amplification would have to be large enough to show the less intense murmurs. With this degree of amplification the deflections of the more intense heart sounds would be so enormous that the record would have to be many feet wide to accommodate them.

Furthermore, the ability of the ear to detect differences in intensity of a sound depends also on the actual intensity of the original sound. For example, at a frequency of about 2,000 c.p.s., an intensity *variation of 5–10 per cent* could be perceived for sound levels *above 50 units of sound intensity;* on the other hand, at the same frequency, a *70 per cent variation* in intensity would be necessary to produce the minimum perceptible change if the actual intensity was only *10 units* (Ongley *et al.*, 1960).

To overcome these difficulties, the sound waves, picked up by the microphone from the chest wall, are during their amplification modified to resemble the sounds heard by the clinician. The relative insensitivity of the human ear to low-pitched sounds is imitated by selectively attenuating the low frequency sounds. This is done by means of electrical filters, incorporated in the amplifying system. This attenuation makes it possible to use sufficient amplification to record clearly the less intense higher-pitched murmurs.

The widely different frequencies and intensities of heart sounds and murmurs present special recording difficulties which can be overcome in various ways. One method consists in splitting the total range of frequencies into several frequency bands, each selected band being recorded separately. A different method, used in this country almost exclusively, is the selective gradual attenuation of lower frequencies to various degrees. This makes it possible to record on the same tracing all medically relevant sounds and murmurs. In practice, three frequency ranges are provided, termed low, medium and high, the clinician choosing whichever is the most informative for a particular purpose.

The way in which attenuation is achieved and frequency ranges are provided is described on p. 112.

Importance of Timing Heart Sounds and Murmurs

Apart from the intensity, duration and pitch of heart sounds and murmurs, their time of occurrence relative to one another, and within the cardiac cycle, is of paramount medical importance.

Simultaneous phonocardiograms from two or more different sites of the precordial area provide information about the time of occurrence relative to one another of acoustic phenomena recorded over

different portions of the heart. Furthermore, sounds and murmurs vary as to the site where they are best heard and recorded.

In order to determine the time of occurrence of a heart sound or murmur relative to the cardiac cycle, that is, to systole and diastole of atria and ventricles, it is necessary to record simultaneously some other indicator of cardiac activity. Such time-reference tracing may be a lead of the electrocardiogram, a tracing of a carotid (artery) pulse or of the jugular venous pulse, or an apexcardiogram. The last mentioned is a record of the pulsations of the chest wall over the apex beat but sometimes a similar record obtained from other parts of the heart (see p. 111). A simultaneous record of breathing, showing the phases of inspiration and expiration, is also often valuable. Many investigators record routinely several of these tracings simultaneously with one or two phonocardiograms obtained from different precordial areas.

Some Physiological Considerations Relevant to Phonocardiography

Every contraction of the normal heart gives rise to two heart sounds, called the *first* and *second* heart sounds. In younger individuals an additional sound, termed the physiological *third* heart sound, is often heard, but is hardly ever present in normal subjects over 40. A further sound is sometimes present which, being due to the contraction of the atria, is called the *atrial*, or *fourth* heart sound. In order to understand the mode of origin of these sounds it is necessary to discuss some additional points regarding the mechanism of cardiac action, supplementing in this respect the description of anatomical and physiological data on pp. 12 *seq.*

During the return of venous blood into the right atrium and that of arterialised blood into the left atrium the atria are relaxed (atrial diastole) and fill. During much of this phase the ventricles are in diastole, the atrio-ventricular valves are open, and blood flows from the atria into the ventricles. Toward the end of ventricular diastole the atria contract (atrial systole), thereby propelling additional blood into the ventricles. When subsequently ventricular systole starts, the pressure in the ventricles rises steeply and the atrio-ventricular valves close. This closure is effected by the apposition of the cusps of these valves, i.e. the mitral and tricuspid valves. This prevents backflow from the ventricles into the corresponding atria and, for a short period of about 0·05 second, both ventricles are closed cavities whence no blood can escape. As soon as the pressure in the left ventricle exceeds that in the aorta, the aortic valves open and blood is rapidly ejected into the aorta. Similarly, the pulmonary valves open when the pressure in the right ventricle exceeds that in the pulmonary artery, and blood is propelled into the pulmonary artery. This phase, called the ejection phase, lasts about 0·2–0·3 second, depending on the heart rate. When this stage is completed, the ventricles relax and the pressure within them drops

rapidly. As soon as that in the left ventricle has fallen below that in the aorta, the aortic valves close. Similarly, as the pressure in the right ventricle drops below the pulmonary artery pressure, the pulmonary valves close. This closure is effected by the apposition of three semilunar folds of which both valves consist; these are therefore also called semilunar valves. For a short period of about 0·08 second the ventricles continue to relax without any blood pouring into them; this phase lasts until the pressure within the ventricles has dropped below that in the corresponding atria, when the atrio-ventricular valves open and blood flows from the atria into the ventricles.

Both the first and second heart sounds are essentially valve-closure sounds.

The *first* sound is mainly due to the closure of the mitral and tricuspid valves by the apposition of their cusps at the beginning of ventricular systole. The closure of the mitral orifice tends to occur slightly before that of the tricuspid, so that the first sound is often split into two components following each other at a short interval (about 0·02–0·03 second; Leatham, 1954, 1958), the first being due to mitral-, the second to tricuspid-valve closure. Other components of the first heart sound, believed by some to contribute to its production, need not be discussed in the present context.

The *second* sound is—for practical purposes solely—due to closure of the semilunar (aortic and pulmonary) valves. In the pulmonary area this sound consists of an aortic and a pulmonary component. Inspiration causes or increases splitting of the second sound over that area, which is due to delay in closure of the pulmonary valves caused by inspiration. During expiration the sound is either single (that is, aortic and pulmonary valves close simultaneously) or split by a short interval of 0·02–0·03 second. During inspiration this interval increases to an average of 0·05 second. Since, in normal subjects, the pulmonary component of the second sound is not transmitted to the apical area, only the aortic component is present, and the sound is single, over that region.

The normal *third* heart sound is most probably due to vibrations of the ventricular myocardium produced by rapid ventricular filling and/or a momentary tensing of the atrio-ventricular valves resulting from it. It is low-pitched, occurring about 0·15 second after the second sound.

The *atrial* or *fourth* sound is also low-pitched and can be recorded by suitable technique. It is due to contraction of the atria and immediately precedes the first sound.

Time-reference Records

It was pointed out earlier in this chapter that the simultaneous recording of additional tracings for the purpose of timing the acoustic

phenomena is of paramount medical importance. The value in this respect of such time-reference records will now be individually discussed. Which and how many of them are taken is largely a matter of the investigator's personal preference and views about their relative value still differ.

Second Phonocardiogram

It is obvious that a second phonocardiogram obtained from a different part of the precordial area is valuable for determining the time of occurrence of sounds and murmurs relative to one another over different portions of the heart, but with certain exceptions provides no direct information about the relation of acoustic phenomena to the mechanical events during cardiac action.

Electrocardiogram

A lead of the ECG (see Figs. 11.1–11.3) with well defined P waves and QRS complexes gives information about the timing of the first heart

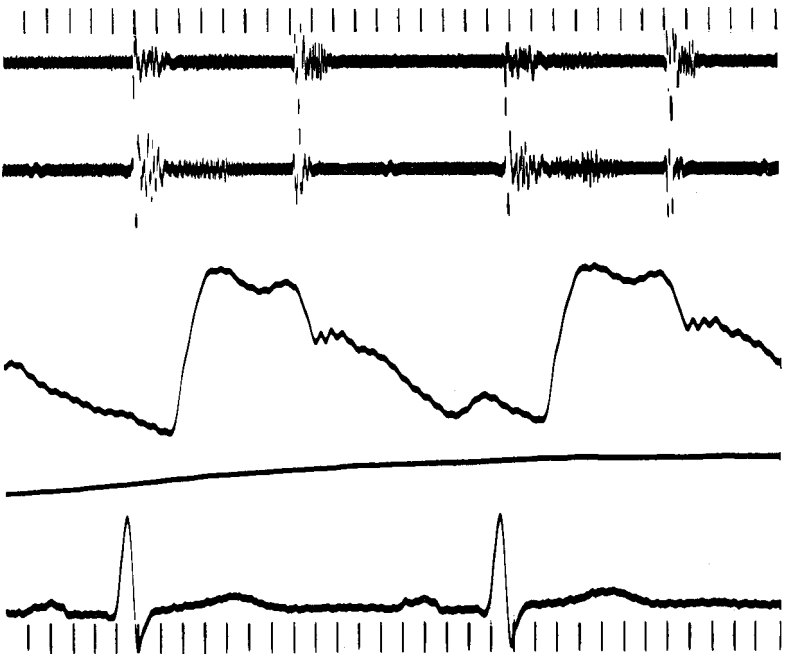


FIG. 11.1. Simultaneous records. From above downward: time base 0·2 and 0·04 second; high frequency phonocardiograms pulmonary area and mitral area; carotid pulse; respiration; ECG lead II; time base 0·2 and 0·04 second.

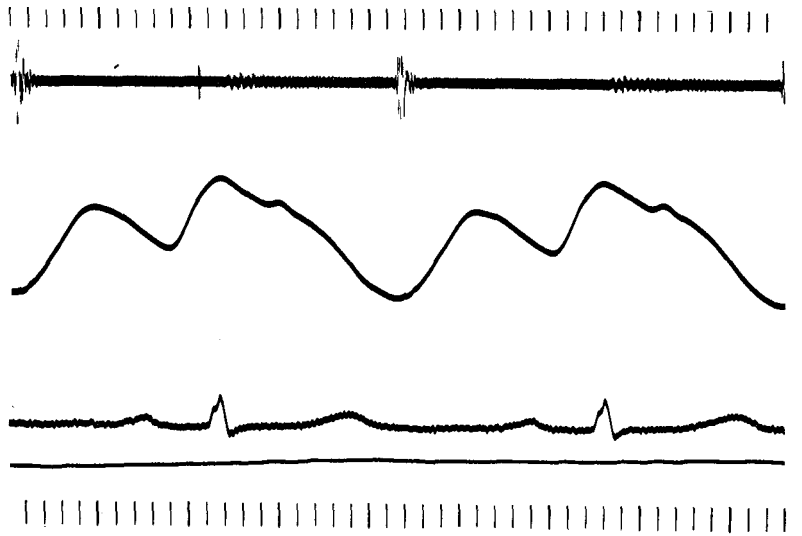


FIG. 11.2. Simultaneous records. From above downward: time base 0·2 and 0·04 second; high frequency phonocardiogram pulmonary area; jugular venous pulse; ECG lead II; respiration; time base 0·2 and 0·04 second.

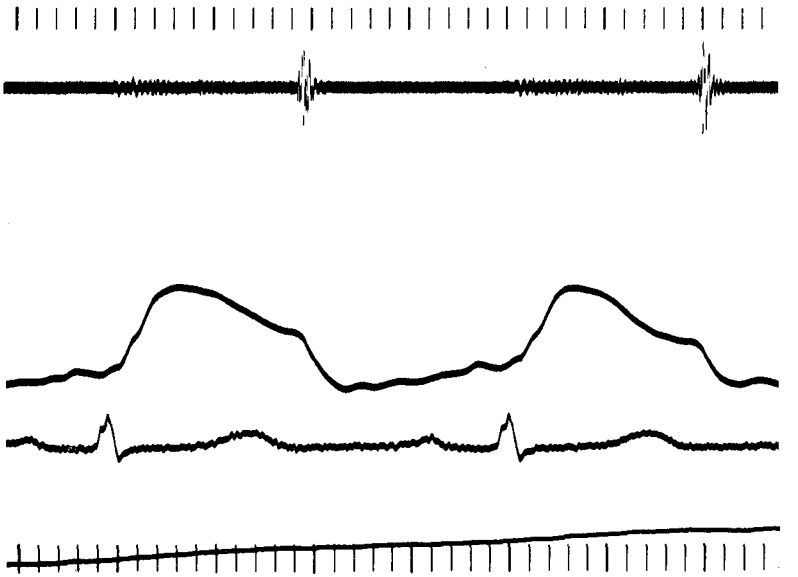


FIG. 11.3. Simultaneous records. From above downward: time base 0·2 and 0·04 second; high frequency phonocardiogram pulmonary area; apexcardiogram; ECG lead II; respiration; time base 0·2 and 0·04 second.

sound which starts about 0·02 second after the beginning of the QRS complex, its maximum occurring 0·02–0·03 second later. The atrial sound starts at about the end of the P wave. The ECG is not suitable for analysis of the second sound.

Carotid Pulse Tracing

This (see Fig. 11.1) reflects changes in the left heart. As soon as blood is ejected from the left ventricle into the aorta, the pressure in the carotid artery rises rapidly and the artery expands. This causes a steep rise in the pulse tracing, its start indicating the moment of the ejection phase of the left ventricle. Allowance has to be made for the slight delay in the pulse wave reaching the carotid artery from the aorta, which is about 0·02 second (Eddleman *et al.*, 1953). The moment of closure of the aortic valves, which marks the beginning of diastole of the left ventricle, produces a sharp dip in the descending limb of the carotid pulse tracing, termed dicrotic notch. This coincides with the aortic component of the second sound, thus making it possible to identify it, and to analyse the second sound over the pulmonary area into an earlier aortic and later pulmonary valve closure sound. The time interval between these two components of the second sound varies with respiration (p. 107).

Jugular Venous Pulse Tracing

This (see Fig. 11.2) provides valuable information for the timing of events in the right side of the heart (because the jugular veins open into the right atrium via the superior vena cava). Normally it consists of three crests and two troughs, termed the *a*, *c* and *v* waves, and the *x* and *y* depressions. The *a* wave, beginning about 0·05 second after the beginning of the P wave in the ECG, is due to right atrial contraction, producing backflow of blood into the veins. The *c* wave is due to right ventricular contraction (elevation and closure of the tricuspid valve) and occurs simultaneously with the first heart sound (Hartman, 1960). This is followed by the *x* depression, due to relaxation of the right atrium, and lowering of the bottom of the right atrium by right ventricular contraction (though the latter is still controversial). As the *x* depression occupies most of ventricular systole it is also called "systolic collapse." At the end of systole, when the ventricles relax but the atrioventricular valves are still closed, the progressive filling of the right atrium produces the ascending limb of the *v* wave. As soon as the tricuspid valve opens, the right atrium empties into the right ventricle, and the fall in pressure in the right atrium results in the *y* depression, also termed "diastolic collapse". The summit of the *v* wave, therefore, coincides with the opening of the tricuspid valve. A normal third heart sound occurs during the descent of the *v* wave, that is, during the time of ventricular filling.

Apexcardiogram

Various methods have been used to record the mechanical pulsations of the chest wall overlying the heart. The value of such apexcardiograms as a time-reference for phonocardiograms has recently been re-emphasised by Benchimol *et al.* (1961), from whose studies the following data are taken. The apexcardiogram (ACG) showing the movements due to the left ventricle is recorded from the site of the apex beat, that due to the right ventricle from the left sternal border in the fourth or fifth intercostal space. The main features of a normal ACG are (see Fig. 11.3): A small *a* wave, due to atrial contraction, can be used to identify an atrial sound in the phonocardiogram. This is followed by a steep rise, the systolic contraction, which reaches its peak when the atrio-ventricular valves close and before the semilunar valves open. The first heart sound usually precedes the peak of this wave by about 0·02 second and, if the first sound is split, both components should be recorded before the peak of the systolic wave of the ACG. This is of medical importance for differentiating a split first sound from certain abnormal sounds which also occur during systole. The systolic wave is followed by a systolic depression, the end of which marks the beginning of diastolic ventricular filling. This filling wave is at first steep, corresponding to the initial rapid ventricular filling, becoming less steep as ventricular filling slows. The second heart sound precedes the beginning of the ascent of the filling wave by 0·04 to 0·08 second. The latter—slow-filling—portion of the filling wave terminates in the *a* wave due to atrial contraction. If a third heart sound is present, it coincides with the end of the steep portion of the filling wave, occurring toward the end of rapid ventricular filling.

INSTRUMENTAL REQUIREMENTS

As already emphasised, the record must reproduce what the physician hears on auscultation.

The essential equipment for recording phonocardiograms comprises:

(*a*) A Microphone.
(*b*) An Amplifier.
(*c*) A Recorder.

Each of these will be briefly described.

Microphone

Two types of microphone are now in common use employing, respectively, the piezoelectric and moving coil principles of operation.

The piezoelectric microphone contains a crystal having a form of lattice structure, which produces a small voltage when a pressure wave, such as a sound, impinges upon it. The voltage is proportional to the fluctuating pressure wave, being of the same frequency as the sound.

Consequently the electrical signal generated will be alternating and can readily be amplified.

The moving coil microphone has a small coil, situated in a magnetic field and held in place by light springs. A diaphragm is attached to the coil and is caused to vibrate by sound waves impinging upon it; this in turn induces a current in the coil, due to its movement in the magnetic field.

Both forms of microphone are often fixed to the chest wall by suction attachment. The surrounding rim, which contains the suction portion, should seat truly so as to be airtight. It is usual to smear the outer rim lightly with vaseline (*not electrode jelly*) to facilitate airtight fitting. Throughout recording great care should be taken to avoid even very slight movement of the microphone, or of the tissue beneath it, since this can cause artefacts and ruin a tracing. Some operators prefer to strap the microphone in position or, alternatively, hold it.

The generated potential is fed to a valve or transistor amplifier whose output energises the recording system.

Amplifier

As discussed earlier in this chapter, in order for a phonocardiogram to reproduce the sounds as heard by the physician, attenuation of lower frequency sounds and selection of certain frequency ranges is necessary. This is achieved by the use of filters.

Filters are usually formed by a combination of resistors, capacitors and occasionally inductors, fitted to the amplifier and switched into the circuit as required. Their purpose is to pass some frequencies without change, but to restrict the passage of others more or less completely. Various combinations of these components are used in phonocardiograph amplifiers to obtain the desired frequency selection.

A control is provided for adjusting the amplitude of the electrical signals in order to produce a record best suited to an individual case. Fine and coarse controls are usually incorporated.

A point for the connection of a stethoscope is also provided for the physician or operator to hear the sounds as recorded, thus enabling him to check the accuracy of the microphone placement and detect the presence of extraneous noises, e.g. borborygmi. A further development is the provision of a number of ear-pieces that may be used by a class of students, thereby facilitating teaching in the recognition and evaluation of different heart sounds and murmurs (Fig. 14.1, p. 130).

Apart from sockets for connecting microphone and stethoscope, the following is a summary of the controls usually provided:

(i) Coarse amplitude control.
(ii) Fine amplitude control.
(iii) Filter switch.
(iv) Volume control for stethoscope.

Recorder

In all forms of heart-sound recorders the galvanometer is of a fixed sensitivity and should possess linear characteristics covering the frequency range of normal heart sounds and of murmurs.

With one exception photographic instruments are used in phonocardiography, since direct writing recorders do not usually possess the requisite frequency response. The exception is the instrument fitted with the fluid jet writing device described on p. 53. One form of instrument employs an ultra-violet lamp source, providing a record for immediate evaluation without photographic processing. If, however, it is desired to make the record permanent, it is necessary to "fix" it by a chemical process.

Phonocardiograms are taken at chart speeds of 50–100 mm/sec.

As already mentioned, it is essential to record a time-reference tracing simultaneously with the phonocardiogram; consequently the recorder must have two channels as a minimum requirement. It is often an advantage to record two phonocardiograms from separate areas simultaneously, in addition to an electrocardiogram and some other indicator of cardiac activity (see pp. 107 *seq.*), also sometimes respiration; four channels are therefore desirable.

The apparatus required for recording carotid or jugular venous pulse, apexcardiogram and respiration are usually supplied by the manufacturers of the multi-channel instruments, together with instructions as to their use.

Recording a Phonocardiogram

It is of paramount importance to produce records having a clear baseline, i.e. free from any extraneous noise which may be picked up by the microphone, and great care must be taken to achieve this. Phonocardiograms must, therefore, be recorded in a quiet room; soundproofing, while not absolutely necessary, is an advantage. Before recording, the patient should be reassured by an explanation of the simple procedure involved. He should be completely relaxed, warm and comfortable, otherwise tensing of the muscles over the precordial area is likely to occur, resulting in a disturbance of the baseline. Care must be taken to avoid leads trailing across the chest since slight movements of these will also disturb the baseline; for the same reason the chest must be clear of clothes. As mentioned previously the microphone must be applied carefully to ensure accurate fit.

If it is desired to take tracings in expiration or inspiration it is advisable to rehearse this procedure before taking the record.

Auscultation should be carried out by a cardiologist to indicate the exact positioning of the microphone. Sometimes it is advisable to mark precisely the areas, because the intensity of the heart sounds may vary over a small area.

When recording a carotid tracing the patient must be in a semi-sitting position, an angle of about 45° usually being suitable; a back-rest should be provided, set at the appropriate angle. On the other hand, a jugular pulse tracing must be taken with the patient recumbent, since with the patient sitting or semi-recumbent the venous pressure is often insufficient to provide a pulse.

Phonocardiographic tracings should always be marked to indicate the frequency filter employed and the exact area over which the microphone was positioned.

Special Techniques

One of the more recent techniques is the intra-cardiac recording of heart sounds. A sensing element, firmly fixed to the tip of a cardiac catheter, is introduced into a vein or artery until its tip reaches the desired location in the heart. The sensing element is connected to the amplifier by wires running through the catheter. The progress and location of the catheter can be ascertained by X-ray apparatus, or by observation of the pressure wave form by means of a conventional manometer. In the latter method, a double lumen catheter is sometimes used. One lumen serves to record intra-cardiac pressures in the usual manner or to withdraw blood samples for analysis; the other lumen contains the wires connecting the sensing element to the amplifier. This method of locating the catheter tip is based on the fact that each chamber of the heart and major blood vessels have characteristic pressure wave forms. The sensing element generally fitted at present to this double lumen catheter uses the principle of varying inductance. In this method, the fluctuating pressure waves of the heart sounds move a diaphragm which, in turn, moves a rod of mumetal. The latter forms a core inside a coil energised by alternating current. The movements of the core alter the inductance of the coil. This gives rise to alterations in the energising alternating current, reproducing electrically the fluctuating pressure waves of the heart sounds. The same sensing element can also be used for monitoring blood pressures electrically by selective circuits in the amplifier. The low frequency signals due to blood pressure waves are separately amplified and fed to one channel of a recorder, the amplified higher frequency signals of the heart sounds being recorded by a second channel.

A different sensing element consisting of a small piezoelectric crystal microphone, similar to that previously described, is also available. This form of pick-up can be fitted to smaller single bore catheters and is therefore suitable for use in patients with small veins, particularly children. Alternatively the piezoelectric pick-up can also be combined with a double lumen catheter and blood pressures monitored with a conventional pressure transducer.

It is claimed that the intra-cardiac microphone technique produces

more useful phonocardiograms, as the sound is picked up at its source and there is thus no distortion by tissue or air spaces interposed between the heart and the surface of the chest. Furthermore, intra-cardiac pressures electrically recorded from a sensing element placed inside the heart are obtained without the delay necessarily present in conventional transducer records. The method is too recent for forming an opinion as to what extent it will necessitate a re-timing of the occurrrence of heart sounds and murmurs relative to the cardiac cycle.

REFERENCES

Benchimol, A., Dimond, E. G., and Carson, J. C. (1961). "The value of the apex-cardiogram as a reference tracing in phonocardiography." *Amer. Heart J.*, **61,** 485.

Eddleman, E. E., Willis, K., Reeves, T. J., and Harrison, T. R. (1953). "The Kineto-cardiogram. I. Method of recording precordial movements." *Circulation*, **8,** 269.

Hartman, H. (1960). "The jugular venous tracing." *Amer. Heart J.*, **59,** 698.

Leatham, A. (1954). "Splitting of the first and second heart sounds." *Lancet*, *2*, 607.

Leatham, A. (1958). "Auscultation of the heart." *Lancet*, *2*, 703, 757.

Ongley, P. A., Sprague, H. B., Rappaport, M. B., and Nadas, A. S. (1960). *Heart Sounds and Murmurs*. Grune & Stratton, New York and London, p. 29.

CHAPTER 12

PROCESSING PHOTOGRAPHIC RECORDS

General Remarks

Electrocardiograms obtained with direct writing instruments and thus immediately available for inspection far outnumber those recorded with apparatus necessitating photographic processing. Photographic recording is, however, used in phonocardiography, with certain types of multichannel recorders, and with string galvanometers which are still employed in some hospitals and research laboratories. A few remarks on certain aspects of photographic processing seem therefore appropriate.

It is not proposed to give details of the chemistry of photographic processing or formulæ for the various solutions; they are fully dealt with in photographic textbooks. Furthermore, makers of photographic papers and films always specify the formulæ and procedures best suited for their products, and manufacturers of the recording instruments usually supply or indicate the type of paper or film to be used with their particular apparatus. There are, however, a few general points on which hints and recommendations may be of use to technicians.

Essential Equipment

The minimum requirements are: a light-proof dark-room with an appropriate safe-light; a sink of adequate size with running water; three containers for developing, rinsing, and fixing (for long records these containers should be tanks, for shorter records dishes may be adequate); a thermometer for checking the temperature of the developer; some clips for handling the records; a few 20-oz graduated flasks for measuring and mixing the solutions; and an automatic dark-room alarm-clock to assess the time of developing.

A thermostatically controlled tank for developing and a rotary glazer are a great advantage.

Developing and Fixing

In choosing the developer it should be borne in mind that a contrasty result is aimed at, that is, the record is required to be as nearly black and white as possible, without half-tones. The makers of photographic materials recommend developers compounded for this purpose. X-ray

developer also gives entirely satisfactory results in some departments.

It is of great importance to develop at the correct temperature, which is indicated by the manufacturers of photographic materials. There is a certain latitude of temperatures producing good results. If, however, the developer is too cold, some of the component chemicals in the solution will crystallize out and become ineffective; if too warm, the action will be unduly rapid and cause grey and flat records or chemical fogging. In either case the result will be disappointing.

When putting the record into the developer it is essential that it be quickly and evenly covered in its entirety by the solution, otherwise uneven results and patches occur which cannot afterwards be obliterated. The period of development varies according to the developer, the speed at which the record was taken, and the intensity of illumination in the instrument. It is necessary to experiment in order to find the optimum period for different developers and grades of paper, and some more experienced technicians determine it by watching the record developing rather than by time-developing. Very approximately, developing time is usually about 3 minutes and should not exceed 5 minutes. If, for whatever reason, a good result is not obtained within this time, continuing development further will not improve the record but, on the contrary, make it deteriorate, rendering it grey and less contrasty.

Stale or exhausted solutions will give weak and stained results. Stale photographic paper (also films) produce similar effects, especially if badly stored.

Most developers will, in time, produce unpleasant brown stains on the fingers and nails which are difficult to remove. It is, therefore, advisable to keep the fingers out of such solutions as much as possible. This can be done by using rubber gloves, or small clips attached to the strips. In no circumstances should the emulsion surface of photographic material be touched by the hands; this is particularly important in warm weather. Even slight perspiration on the fingers will contaminate the emulsion, and cause unsightly fingermarks and stains on the finished record which cannot be removed.

After development the record should be thoroughly rinsed in clean water before transferring it to the fixing solution. A stop-bath is preferable to water only, as it arrests development immediately and thus prevents any further uneven developing as well as transferring any traces of active developer into the fixing solution. Traces of developer, which may otherwise have been left on the emulsion before putting the record into the fixing bath, are likely to cause stains.

The most suitable fixing bath is an acid hypo solution with hardener incorporated. Here again it is essential that the entire record is fully immersed in the bath. A fixing period of 5 minutes is usually sufficient; more than 10 minutes should never be necessary, unless the solution is getting exhausted, in which case it requires renewing.

Washing and Drying

After fixing, the record should be thoroughly washed in running water for a minimum of 30 minutes, preferably 1 hour, in order to remove even the most minute traces of hypo; otherwise the record will not be permanent and, in the course of time, may develop stains and deteriorate generally.

After washing, the record must be dried and should preferably be glazed. In either case it is good practice to immerse the record, after washing, in water to which a few drops of wetting solution (obtainable from photographic dealers) have been added. This lowers surface tension and thus hastens drying.

If the record is only to be dried, this is best done in a dust-free atmosphere where air can circulate freely. An electric fan may be used with advantage. On no account should any photographic record be dried by a fire or uncontrolled heat.

It is far preferable to glaze such records, since this improves their appearance, makes them more durable, and is essential for their reproduction in a publication. Rotary glazers, particularly suitable for treating long records, are obtainable.

If, in emergencies, records are very quickly required, it is possible to shorten the washing time considerably by immersing them, after fixing, in a weak solution of permanganate of potassium which neutralises the hypo; and, in such circumstances, drying can be hastened by soaking the records for a few seconds in methylated spirit. Neither of these expedients is recommended as a practice, since the finished records may not be permanent.

Some Remarks Concerning the Processing of Films and Prints

Recording on films of the formerly standard size of $3\frac{1}{4} \times 6\frac{3}{4}$ inches is nowadays done in only so few hospitals that this technique no longer warrants any detailed description. Tank development is also suitable for films and recommended particularly if large numbers have to be processed. Frames of a suitable size should be used which ensure quick and even immersion of the film in the solution. In view of the standard size of these films, small by comparison with the long strips now routinely taken in many instances, processing may also be carried out in dishes of suitable sizes; this method commends itself particularly if small numbers are concerned. Contact prints are then made from the films in printing frames of the correct size, or using a printing box. It is important to ensure that the photosensitive surface of the printing paper is in contact with the emulsion (or dull surface) side of the film. The film should be laid with the glossy side nearest the glass of the printing frame or box. It is important to guard against putting in the film in the reverse direction, that is, with the emulsion side down-

wards since, in this event, the print will be reversed as a mirror image and practically useless for interpretation. The same considerations stressed above regarding contrasty results apply also to the development of films and prints. Glazing of the prints after washing, which is advisable, can also be done by means of a ferro type or highly polished steel plate (obtainable from photographic dealers), but with larger numbers of prints an electrically-heated glazing apparatus is a distinct advantage.

CHAPTER 13

THE VECTORCARDIOGRAM*

THE object of vectorcardiography is to provide a graphic representation of the changes of electrical potential in the heart as they occur in space, that is, in three dimensions.

A lead of a conventional electrocardiogram shows the projection of the three-dimensional potential changes on to one *line* in one plane, namely, the line of the lead. The lead therefore represents the changes as projected in *one* dimension. If a tracing more closely reproducing the three-dimensional changes is desired, the projection of the potential changes on to one *plane*, that is, in *two* dimensions, can be recorded. Such a record is termed a *vectorcardiogram.*

If the electrical changes are simultaneously recorded in *two planes* standing at right angles to one another, such records can be used for the construction of a *three-dimensional* model (for example, in wire) to depict the course in space of the electrical changes in the heart. This is called a *spatial vectorcardiogram.* As the making of such models is a very time-consuming procedure, it is rarely used and only for special purposes.

In practice, the recording of the potential changes in three planes standing at right angles to one another, namely, the frontal, sagittal, and horizontal (transverse) planes (Fig. 13.1) is the usual method. To record these vectorcardiograms an entirely different instrument is required, and such records differ radically from conventional electrocardiograms.

The concept of an electrical vector as a quantity having a definite length, direction and "sense" has been explained above (p. 30). During a heart beat the length as well as the direction in space of the momentary vector change from moment to moment; during periods of electrical quiescence there is no vector. If the rhythm is constant, the vector passes through the same movements with each contraction. Its "arrowhead" describes closed loops in space; closed because during periods of electrical quiescence it returns to the same place whence it started. In the leads of a conventional electrocardiogram—such leads being collectively called "scalar" leads—the periods of electrical quiescence (P–Q, S–T and T–P segments) are indicated by iso-electric lines; in vectorcardiograms, electrical quiescence results in the return of the

* This chapter may be omitted, particularly at the first reading, by those not especially interested in the subject.

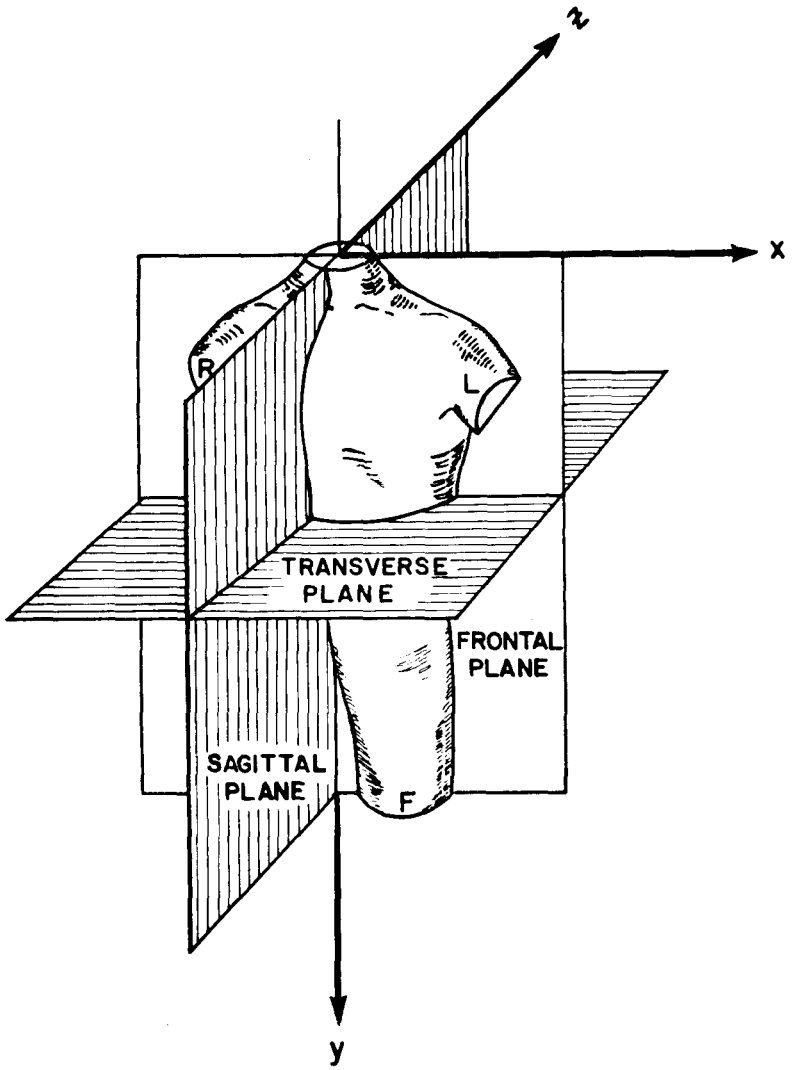


FIG. 13.1. Diagram of a human torso illustrating horizontal (transverse), frontal and sagittal planes. *x*, *y*, *z* indicate horizontal, vertical and sagittal axes. From Frank, 1954, *Circulation*, **10**, 101.

tracing to, and temporary rest at, the point of origin of the vector loop.

With normal heart rhythm three such loops are recorded with each contraction, corresponding to the P, QRS, and T deflections (Fig. 13.2). The QRS loop is the largest, the P loop the smallest, the T loop intermediate in size.

The vectorcardiogram of one plane can be constructed from component scalar leads simultaneously recorded in that plane; conversely, the component leads in a plane can be constructed from a vector-

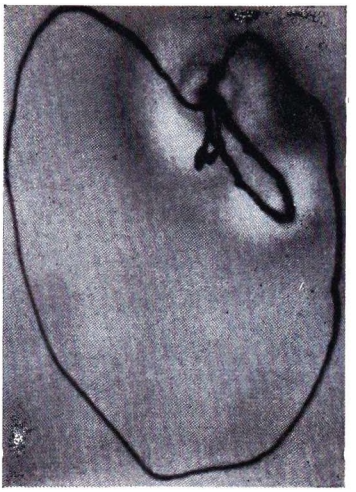


FIG. 13.2. The normal vector loop. From Schellong, 1939, *Erg. inn. Med. Kinderheilk.*, **56,** 657.

cardiogram recorded directly in that plane. The latter procedure will be discussed first.

The principle of recording a vectorcardiogram (VG) may be exemplified by the frontal VG. The movements of the vector in the frontal plane are composed of movements in the horizontal and vertical

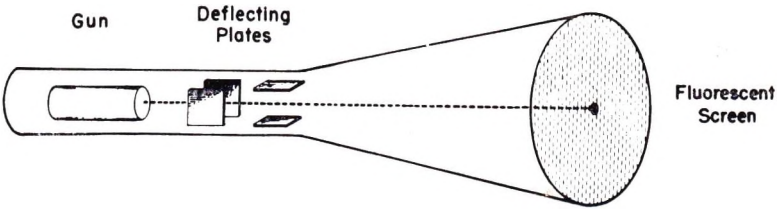


FIG. 13.3. Diagram of cathode-ray oscillograph. From Burch, Abildskov and Cronvich, 1953.

directions. The resultant (p. 30) of these movements during the periods of atrial and ventricular de- and re-polarisation constitutes the frontal VG. This resultant is obtained by the simultaneous recording of the horizontal and vertical movements of the vector throughout a cardiac contraction. It is done by a cathode-ray oscillograph (Fig. 13.3).

This consists of an evacuated glass tube, containing an anode and a cathode. The latter emits a stream of electrons (cathode-ray) which produces a luminous spot where it hits a fluorescent screen. The cathode-ray can simultaneously be deflected in the horizontal and vertical directions by two pairs of metal plates, placed respectively at right angles to one another (Fig. 13.4). To one pair are fed the amplified potentials of a horizontal lead—for example, lead I—and to the other, those of a vertical lead, for example, lead VF (Fig. 13.5). Electrical

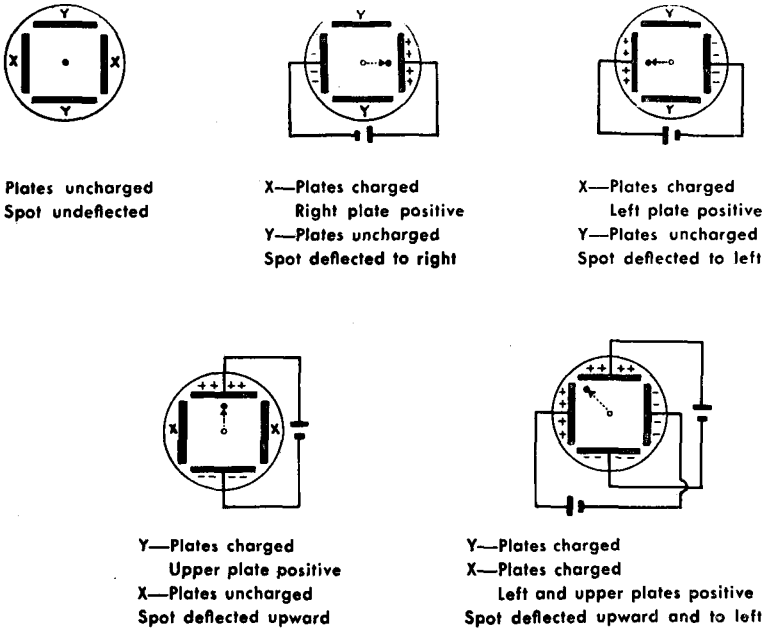


FIG. 13.4. Diagram of deflections of cathode-ray beam by electrical charges on the deflecting plates. From Burch, Abildskov and Cronvich, 1953.

charges on the first pair of plates, alone, deflect the beam in the horizontal direction, those on the second pair, alone, in the vertical one. The combined effect of charges on the two pairs of plates produces a simultaneous deflection in both directions which is, within wide limits, proportional to the algebraic sums of the potentials in the two leads employed. The tracing reproduced in Fig. 13.2 was obtained in this way. Similarly, loops can be recorded in the horizontal and in the sagittal plane by simultaneously recording two leads, respectively, in each of these planes. The sites of placement of the recording electrodes is chosen so as to provide in each plane two leads at right angles to one another.

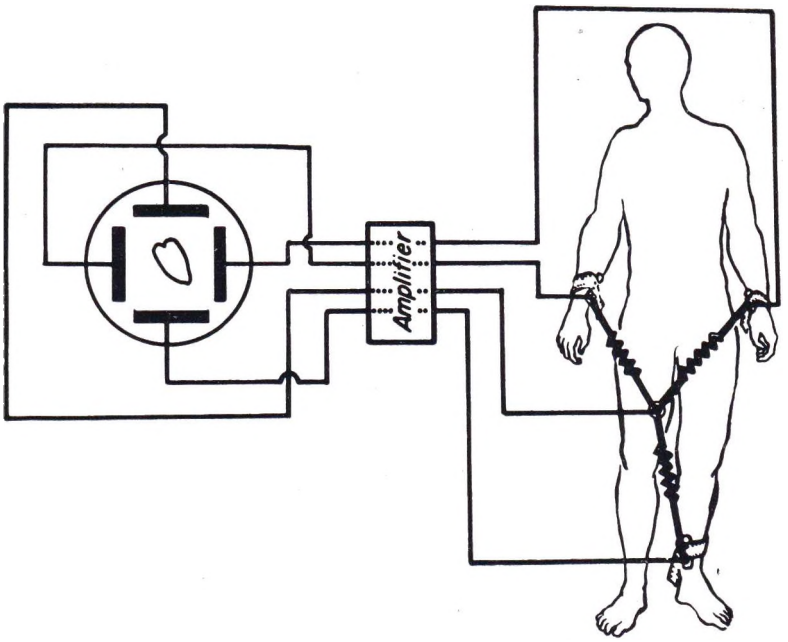


FIG. 13.5. Electrode connections to oscilloscope plates for the frontal plane projection on cathode-ray screen. From Burch, Abildskov and Cronvich, 1953.

The velocity of the vector movement is indicated in the VG by a time base incorporated in the tracing, which is achieved by electrically extinguishing the cathode-ray at regular intervals. This makes the tracing appear as an interrupted line, that is, a series of dashes (Fig.13.6).

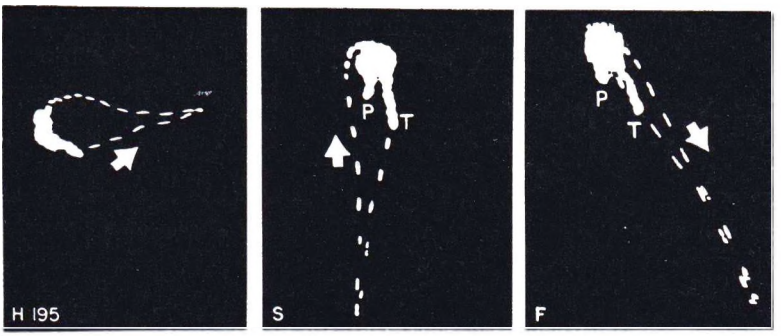


FIG. 13.6. Horizontal (H), sagittal (S), and frontal (F) vectorcardiograms of a normal subject. From Grishman and Scherlis, 1952.

The direction of rotation of the loop can be indicated by the shape of these dashes. Investigators differ in their choice of time base (varying between 0·2 and 0·04 second).

Theoretically and ideally, all electrodes used in vectorcardiography should have the same distance from one another and also from the electrical centre of the heart. In practice this is not possible and there is as yet no unanimity amongst the various investigators regarding the best placement of the electrodes. Three methods are illustrated in

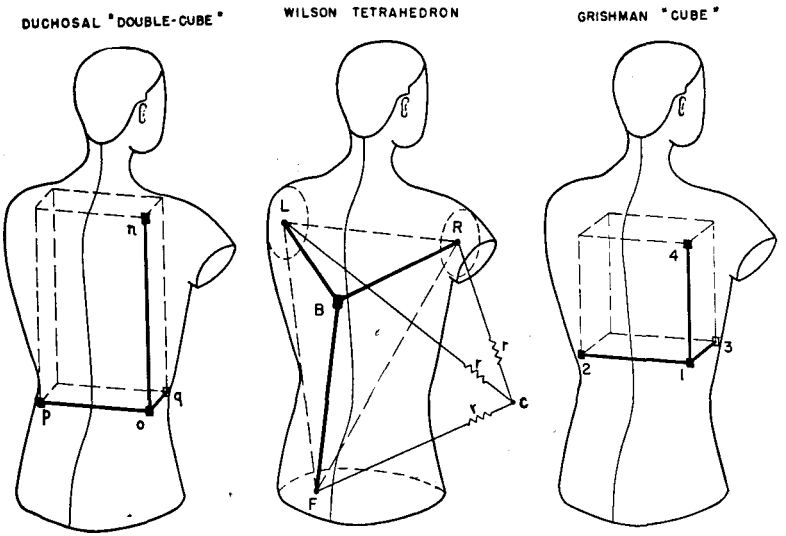
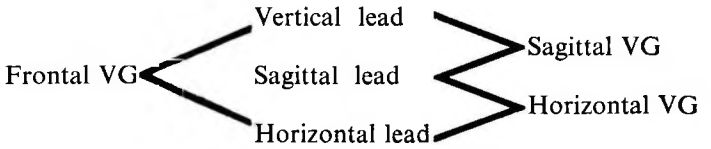


FIG. 13.7. Schematic illustration of the electrode arrangements employed in three commonly used systems of vectorcardiography. Letter and number identifications for the electrodes as originally presented are retained. The solid squares indicate electrodes placed on the back of the subject. The standard limb electrodes are indicated by R, L and F. A central terminal C is connected through equal resistors, r, to R, L, and F. From Frank, 1954, *Circulation*, **10**, 101.

Fig. 13.7. In Wilson's tetrahedron (see figure) the frontal VG is obtained from leads I and VF, which is the method used in the example given earlier in this chapter. The sagittal VG: its horizontal component is obtained by pairing an electrode placed on the back, 2 cm to the left of the seventh dorsal vertebra (point marked B on the figure) with Wilson's Central Terminal; its vertical component by lead VF.

Much work has recently been done on the problem of improving electrode placement (see Pozzi, 1961). Whichever method is used, the individual leads composing the vectors in the frontal, sagittal and horizontal planes can be indicated thus (after Duchosal and Sulzer):



The way in which the component leads can be constructed from a directly recorded VG, namely, by drawing the projections of the vector loop on to the lines of the leads in the particular plane, is illustrated in Fig. 13.8. This is an example of a frontal VG, projected on to the three standard bipolar limb leads.

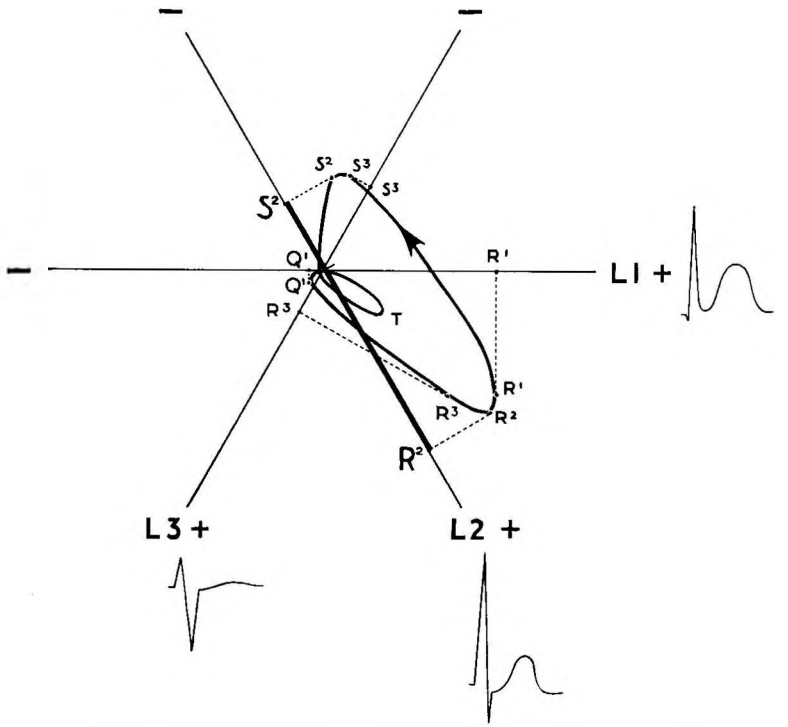


FIG. 13.8. The principle of constructing the three standard bipolar limb leads from a frontal vectorcardiogram. The axes of these leads are indicated by three lines with an angle of 60° between each other. The point of intersection of these lines marks the electrical zero. Positive potentials to one side, negative to the other side, as indicated by + and — signs. Broken lines indicate lines of projection of the vector loop on to the axes of leads 1, 2 and 3. Projection on to the + portion of an axis yields an upright deflection in the lead of that axis, its maximum corresponding to the peak of the R wave. Projection on to the — portion yields a downward deflection, its maximum corresponding to the lowest point of the S wave. On the axis of lead 2 these two portions are marked by a thicker line.

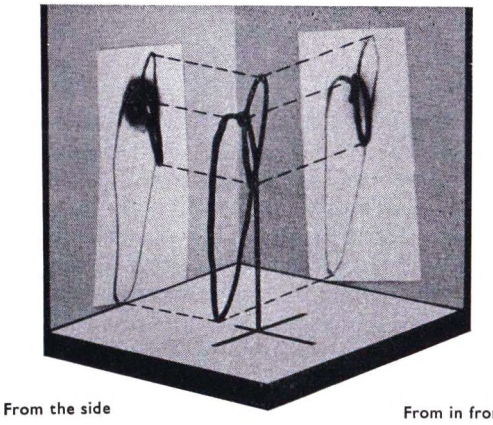


FIG. 13.9. Construction of a three-dimensional (wire) model of the vector from frontal and sagittal vectorcardiograms. From Schellong, 1939, *Erg. inn. Med. Kinderheilk.*, **56**, 657.

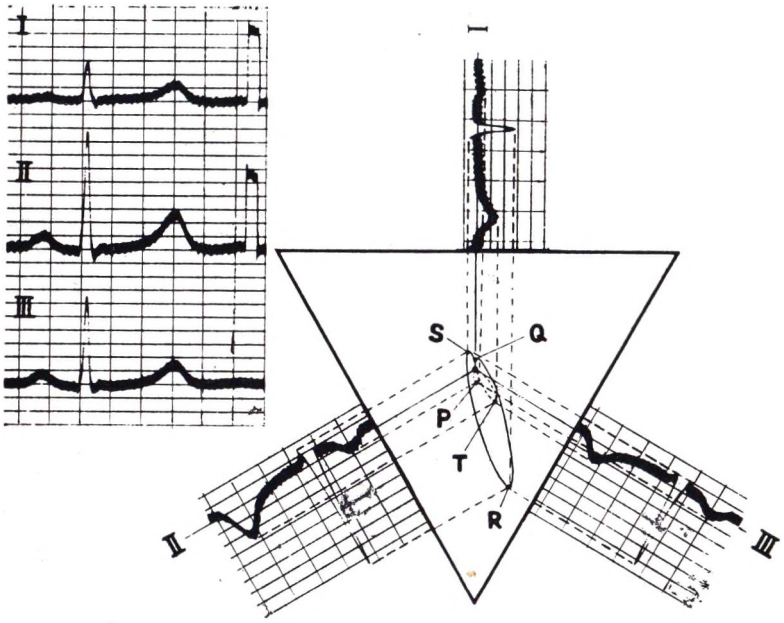


FIG. 13.10. The principle of constructing the vector in the frontal plane from the three standard bipolar limb leads. From Holzmann, 1961.

From vectors recorded in two planes standing at right angles to one another, spatial vectors can be constructed, as mentioned above. This is illustrated in Fig. 13.9, exemplified by frontal and sagittal vectorcardiograms.

Conversely, the vectorial loop in a plane can be constructed from component conventional leads simultaneously recorded in that plane. *Taking again the frontal vector as an example, its construction from* the three standard limb leads is shown in Fig. 13.10. The three standard leads are placed in such a way that the ordinates of each lead are parallel to the direction of the lead recorded. This direction is represented by the sides of an equilateral triangle in accordance with Einthoven's concept (see above p. 26). By drawing the projections of the deflections of each lead at certain intervals on to the axis of the lead, the frontal vector can be constructed by joining the points of intersection of these lines of projection. It is seen that the vector is a loop. This construction shows also the direction of rotation of the loop. Similarly, the sagittal and horizontal vectors can be constructed from leads simultaneously recorded in the sagittal and horizontal planes, respectively.

The greater the number of points used to determine such a vector, the more accurate its construction. A special drawing instrument was designed for this purpose, whereby the points of the vector are determined at intervals of 1/200 second (Shillingford and Brigden, 1951).

This short description of vectorcardiography is deliberately simplified. Despite the great number of publications on the subject, the method is still in its experimental stage. To what extent vectorcardiography will in future supplement or replace scalar lead electrocardiography is impossible to foretell.

REFERENCES

Burch, G. E., Abildskov, J. A., and Cronvich, J. A. (1953). *Spatial Vectorcardiography*. Kimpton, London.

Duchosal, P. W., and Sulzer, R. (1949). *La Vectocardiographie*. Karger, Basle. Bibl. cardiol. Fasc., **3.**

Frank, E. (1954). "A direct experimental study of three systems of spatial vectorcardiography." *Circulation*, **10,** 101.

Goldberger, E. (1953). *Unipolar Lead Electrocardiography and Vectorcardiography*, 3rd ed. Kimpton, London.

Grishman, A., and Scherlis, L. (1952). *Spatial Vectorcardiography* Saunders, Philadelphia and London.

Holzmann, M. (1961). *Klinische Elektrokardiographie*, 4th ed. Thieme, Stuttgart.

Pozzi, L. (1961). *Basic Principles in Vector Electrocardiography*. Kimpton, London.

Schellong, F. (1939). "Grundzüge einer klinischen Vektordiagraphie des Herzens." *Erg. inn. Med. Kinderheilk.*, **56,** 657.

Shillingford, J., and Brigden, W. (1951). "The vectorcardiogram in 100 healthy subjects using a new drawing instrument." *Brit. Heart J.*, **13,** 233.

Wilson, F. N., Bryant, J. M., and Johnston, F. D. (1949). "On the possibility of constructing an Einthoven triangle for a given subject." *Amer. Heart J.*, **37,** 493.

Wilson, F. N., and Johnston, F. D. (1938). "The vectorcardiogram." *Amer. Heart J.*, **16,** 14.

Wilson, F. N., Johnston, F. D., and Kossman, C. E. (1947). "The substitution of a tetrahydron for the Einthoven triangle." *Amer. Heart J.*, **33,** 594.

CHAPTER 14

SPECIAL CARDIOLOGICAL EQUIPMENT

THE main object of this work has been to deal with standard cardiographic equipment. In addition, reference has been made to procedures not so commonly employed, such as phonocardiography and vectorcardiography. The former, whilst not yet universally employed, is becoming standard practice in an increasing number of hospitals; the latter is attracting increasing interest particularly in the U.S.A. Both thus come under the care of cardiological technicians.

In teaching hospitals or universities and in institutions giving postgraduate instruction additional apparatus may be installed which is of particular value for lecture work. Among such instruments is the Audio-Visual Heart Sound Recorder (Fig. 14.1). This instrument has been developed for the dual purpose of clinical use and teaching purposes. It is designed to detect heart sounds and murmurs in the usual manner by a microphone placed on the chest, the sounds being recorded on a magnetic disc. The discs are of special plastic, the thickness of a sheet of paper, and are extremely durable, permitting them to be filed with a patient's notes or sent through the post. The provision of a stethophone and a 3-inch cathode-ray oscilloscope (with a long persistence screen) permits the sounds to be simultaneously heard and seen. The instrument has four channels enabling four consecutive recordings to be taken. When no longer required, the records can be erased magnetically and the discs used again. However, a library of discs with typical sounds can be built up and provides a useful means for teaching. A system of multiple sockets with additional stethophones can be fitted to the recorder so that several individuals may listen to the sound recordings, simultaneously viewing their pattern on the screen of the oscilloscope. This combination has proved a valuable help in teaching. The persistence of the screen is such that the entire pattern remains visible until it repeats.

If a timing signal is required a direct writing electrocardiograph can be connected to the Audio-Visual Heart Sound Recorder, the R wave of the patient's electrocardiogram introducing a high pitched note, which is heard on the stethophone and also seen on the tracing as it is displayed. This timing signal is also placed upon the magnetic disc record and is then heard and seen when the record is played back.

In some cardiovascular investigation centres, the diversity of investigating techniques often makes it desirable to record several

phenomena simultaneously. For this reason multichannel recorders (see Fig. 14.2) are now widely used. These instruments consist of a basic recording system and interchangeable pre-amplifier units and trans-

FIG. 14.1. Audio-visual heart sound recorder, manufactured by Cambridge Instrument Co. Inc., New York 17, N.Y., U.S.A.

ducers thus enabling the simultaneous recording of a wide variety of biological data. Among available pre-amplifiers are units for recording electrocardiograms, phonocardiograms, electroencephalograms (brain potentials), electromyograms (muscle potentials), intra-vascular pressure, peripheral pulse waves, dye dilution curves, blood pH, and others.

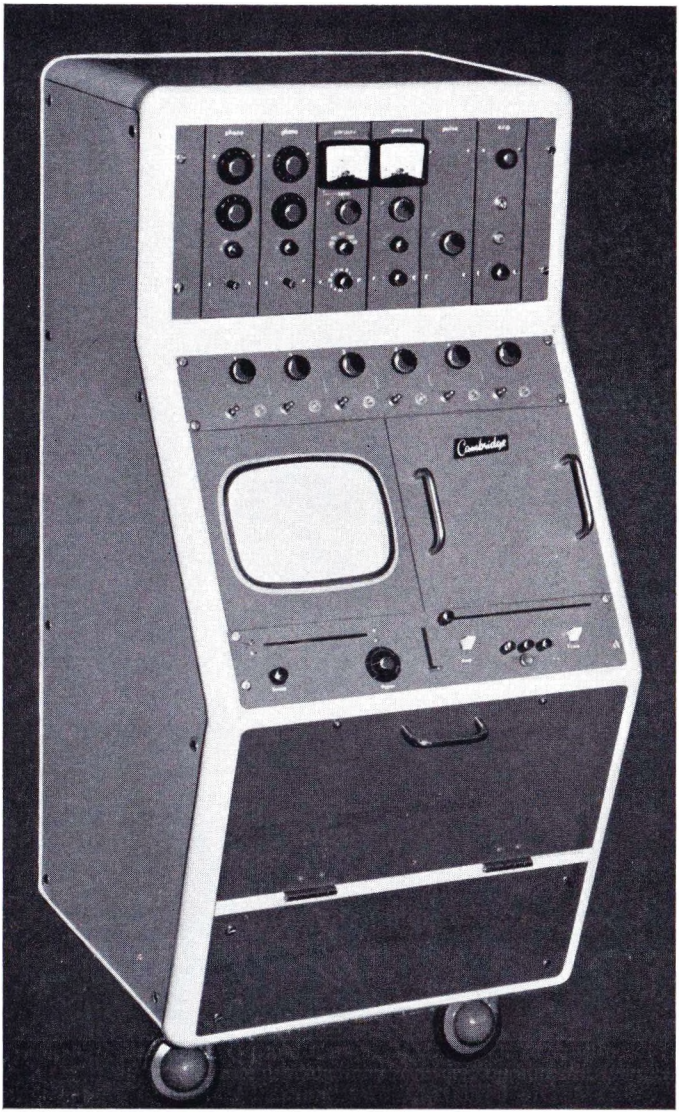


Fig. 14.2. Photographic multichannel recorder, manufactured by Cambridge Instrument Co. Ltd. (Type A).

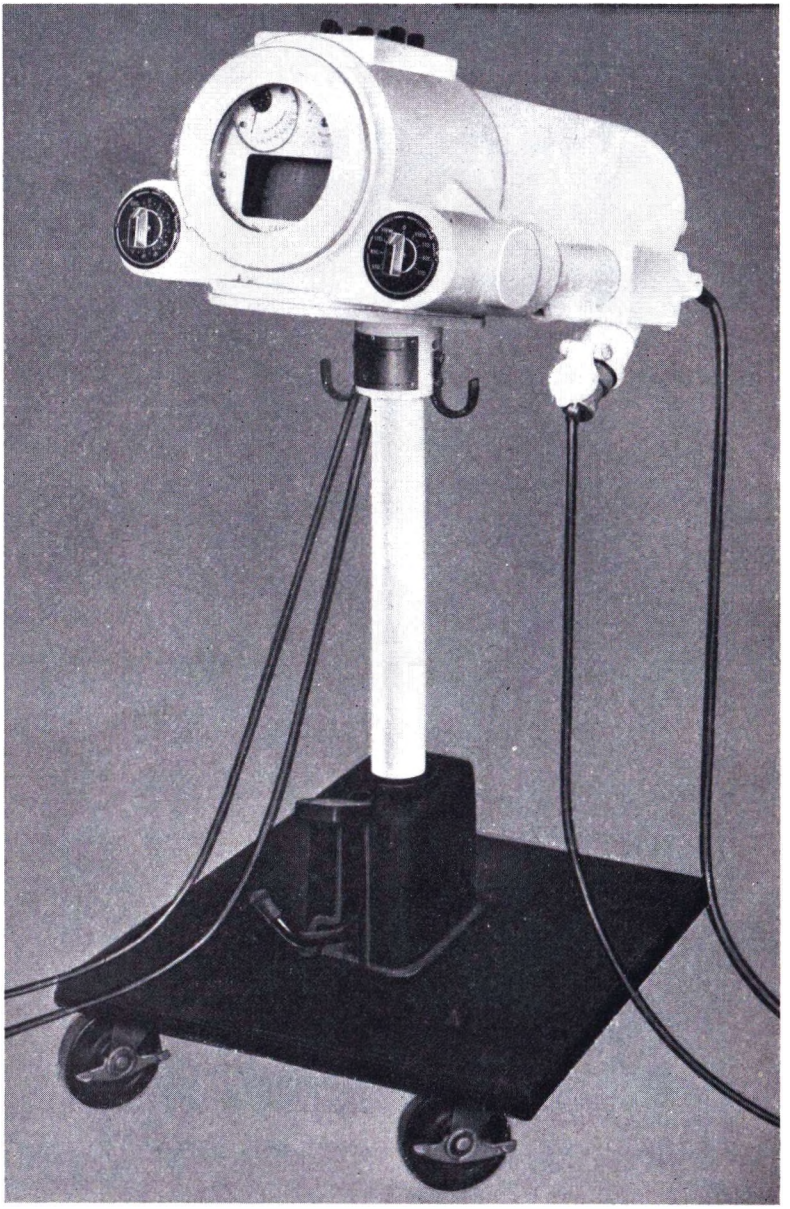


FIG. 14.3. Operating room cardioscope, manufactured by Cambridge Instrument Co. Inc., New York 17, N.Y., U.S.A.

Various forms of recording systems are employed, but in general they fall into two categories—photographic and direct writing.

The *photographic* system is used for high frequency recordings, this method also permitting the superimposition of tracings and the utilisation of the full width of the recording paper when desired.

The *direct writing* system is employed for low frequency recordings and for obtaining records to be viewed immediately without the delay of photographic processing.

A range of chart speeds is usually provided, making it possible to select the most suitable one for an individual purpose.

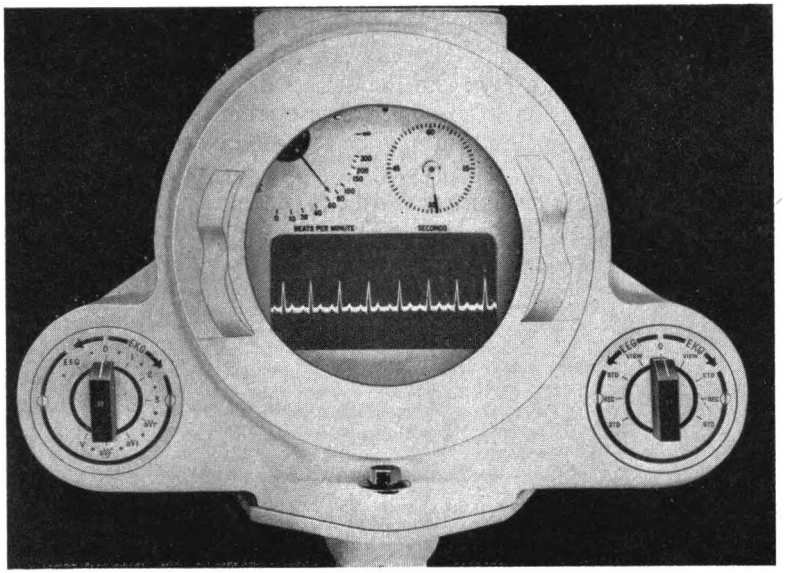


FIG. 14.4. Detail from Fig. 14.3.

A multi-beam cathode-ray oscilloscope is frequently used in conjunction with these outfits to provide visual information to the surgeon or anæsthetist.

An electrocardiographic monitor is often available to anæsthetists for use during surgical operations, thus enabling them continuously to observe the rate and rhythm of the patient's heart during surgery. The apparatus is placed so that the screen may readily be seen by the anæsthetist throughout the operation, without obstructing the surgeons and their staff. Figs. 14.3 and 14.4 illustrate an instrument designed for this purpose. The long persistence 5-inch cathode-ray screen continuously indicates any selected lead of the electrocardiogram as well as the

instantaneous heart rate, or the patient's electroencephalogram. The latter is a valuable aid for indicating depth of anæsthesia. Above the cathode-ray tube is a second-hand to assist in the counting of pulse rates and also to facilitate the setting of the sweep rate of the cathode-ray tube to a desired speed. A cardiac standstill alarm in the form of a buzzer is incorporated in the instrument, providing an insistent but unobtrusive audible warning when the heart rate drops to any preset level below 60 beats per minute. The heart rate indicator is scaled from 0 to 300 beats per minute. The whole apparatus is enclosed in an explosion-proof housing, which makes it entirely safe for use in an operating theatre where explosive gas mixtures may exist.

A remote control switch is fitted to the monitor enabling either the electrocardiogram or electroencephalogram to be recorded on a direct writing electrocardiograph, which may be situated at a distance from the operating theatre, away from the danger of explosive mixtures. In this manner, in addition to viewing either tracing on the cathode-ray screen, any desired portion of it may be recorded by the electrocardiograph.

Such apparatus has become standard equipment in a large number of hospitals, particularly in the United States.

GLOSSARY

OED = *Oxford English Dictionary*. CTD = *Chambers's Technical Dictionary*

ALGEBRAIC SUMMATION: The addition of symbols (for example, a, b, x, y, etc.) or figures whereby those with a + sign are added and those with a − sign subtracted.

ALLOY: Metal prepared by adding other metals or non-metals to a basic metal to secure desirable properties (CTD).

ALTERNATING CURRENT: A current which reverses its direction at regular intervals (OED).

AMPLITUDE: The maximum height or depth of a deflection.

ARMATURE: A moving part situated in a magnetic field. Used to indicate the presence of an electric current.

ATTENUATE: To reduce in value.

CAPACITOR (previously CONDENSER): A component of an electrical circuit, consisting of two conducting plates separated by a layer of insulating material. Used as part of an electrical filter in phonocardiography.

CAPACITY of a battery: The measure of the quantity of electrical energy which can be obtained from it.

CARDIAC CATHETER: A flexible tube which may be introduced into a vein or artery and thence manipulated into a chamber of the heart or great vessel, commonly used for withdrawing blood samples and recording intracardiac pressure.

CONDUCTOR: A material which offers a low resistance to the passage of an electric current (CTD).

CONGENITAL: Existing at birth.

DEAD BEAT: For a galvanometer movement to be "dead beat" it should take up its full deflection with the necessary rapidity without overshooting.

DIRECT CURRENT: A current flowing in one direction only.

ELECTROMOTIVE FORCE: The force which tends to cause a movement of electricity around an electric circuit (CTD).

EMISSION: The process of ejection of electrons from a conducting surface by means of heat.

FREQUENCY (BAND): The number of complete cycles per second of an alternating current (OED). F. BAND: A defined range of frequencies.

GALVANOMETER: An instrument for detecting and measuring electric currents; in certain circumstances also for determining their direction.

HELICAL SPRING: A coiled spring similar in form to the thread of a screw.

IMPEDANCE: Apparent resistance to an alternating current.

INDUCTOR: Usually a coil of wire which tends to impede the passage of an alternating current. Sometimes used as a component of filters in phonocardiography.

INERTIA: That property of matter by virtue of which it continues in its existing state, whether of rest or of uniform motion in a straight line, unless that state is altered by external force (OED).

INSULATOR: A material offering such high resistance to electric current that it impedes its passage.

ISO-ELECTRIC LINE: Another word for baseline in ECGs, which is recorded during intervals when no current flows through the galvanometer.

LATTICE STRUCTURE: The network arrangement of groups of atoms of a specific regularly recurring pattern in a crystal.

LINEAR: For galvanometer deflections to be linear the deflections must be directly proportional to the applied current.

POTENTIAL: When a point is said to be "at a certain potential", the meaning is there is a potential difference of that amount between the point and earth (CTD). The potential of earth is zero.

RESISTANCE: The property of a substance of resisting the flow of an electric current through it.
RESISTOR: A component acting as a resistance (*q.v.*).
RHEOSTAT: A variable resistance used to adjust the current to a desired value.
SCREEN: A device which protects an electrical apparatus from external electric or magnetic influences (OED).
SHORT CIRCUIT: To connect, or the connection between, two points of an electrical circuit by a very low resistance approximating zero.
SIGNAL: The electrical changes which it is desired to record.
SKELETAL MUSCLES: Striated muscles other than heart muscle, performing voluntary movements, as distinct from unstriated muscles performing involuntary movements (for example, contraction of stomach).
SOMATIC TREMOR: Tremor of skeletal muscles.
SURFACE TENSION: The tension of the surface-film of a liquid, due to the cohesion of its particles.
WATT: The unit of electric power.

INDEX

***a* wave,** 110, 111
Action current, di-phasic, 10
Alternating current interference, 90–92
  elimination, 92
  sources, 91
Amplifier for phonocardiography, 112
  for transistor-operated cardiograph, 66
  for valve-operated cardiograph, 50
Amplifying valve, 48
Amplitude, range of normal in the various leads, 37, 38
Anæsthetists, electrocardiographic monitor for, 133
Apexcardiogram, 5, 111
Application of electrodes, 77–85
Atria, 12–18
Atrial sound, 106, 107
  wave, in apexcardiogram, 111
    in electrocardiogram. *See* P wave
    in jugular venous pulse tracing, 110
Atrio-ventricular node, 16
  orifice, left, 12
    right, 12
  system, 16
Audio-visual heart sound recorder, 129
Auricles. *See* Atria
Auricular appendages, 12

Bundle of His, 16, 18
Burger suction electrode, 84

***c* wave,** 110
Camera for string electrocardiograph, 43
  for valve-operated cardiograph, 51
Capillary jet fluid recorder, 53
Cardiograms, Cambridge mount for, 97
Cardioscope for operating-room use, 132, 133
Carotid pulse tracing, 106, 110
Cathode-ray oscillograph for vectorcardiogram recording, 122, 123
Cell, electrical behaviour of, 7
Chest electrodes, 21, 84
  application of, 81
  leads, 21, 81
    introduction of, 4
    unipolar, introduction of, 4
Classification card index of electrocardiograms and reports, 102
Control panel of string electrocardiograph, 43
  of transistor-operated electrocardiograph, 74
Control panel—*contd.*
  of valve-operated electrocardiograph, 54
Currents, interfering. *See* Alternating current interference

Date index of electrocardiograms and reports, 100
Depolarisation, 7–10, 20
Developing and fixing, 116
Diastole, 16
Di-phasic action current, 10
Direct-writing recorders, 51, 71
Duchosal's "double-cube", 125

Earth connections, 58
Einthoven's law, 26
  early work on electrocardiogram, 3
  on phonocardiogram, 5
  limb leads, 3, 21
  string galvanometer, 4, 5, 42
  triangle, 26
Electrical axis, 30. *See also* Vector
Electrocardiogram, definition of, 7
  effect of heart position on, 33
  historical development, 3
  indexing and filing of, 99–103
  initial ventricular deflection, 20
  leads, 21. *See also* Leads
  mounting of, 96–98
  nature of, 7–10
  normal, component parts, physiological significance, 18
    cycle of, 19
    features and factors influencing, 11–39
  recording procedure for, 85–89
  taking, 76–89
    positioning patient for, 76
  terminal deflection, 20
Electrocardiograph, direct-writing, 45, 62, 133
  multi-channel, 130
  servicing of, 95
  special equipment, 129–134
  string, 42–44
    components of, 42
    control panel, 43
    history of, 3
    illuminating system of, 43
    principle of operation, 44
    recording camera for, 43
    standardisation of, 43
    time-marker, 43

Electrocardiograph—*contd.*
transistor-operated, 62–75
amplifier for, 66
components, 66–75
control panel, 74
printed circuit for, 67–71
recorders, 71
standardisation of, 74
valve-operated, 45–61
amplifier for, 50
components of, 50
control panel, 54
fuse plate, 57
interference eliminator, 57
mains connection for, 55
muscle tremor suppression in, 58
record marking device for, 57
recorders for, 51
standardisation of, 55
switch, half-sensitivity for, 57
Electrode jelly, 77
Electrodes, 21, 22, 77
application of, 77–85
Burger's suction type, 84
cleaning of, 78
exploring, 21–26
fixing of, 79, 80
indifferent, 21–26
introduction into heart muscle cell, 40
œsophageal, 85
placement in vectorcardiogram, 125
wet-pad, 84
Electromagnetic interference, 90
Electron theory, fundamental principles of, 47
Electrostatic interference, 90
Exploring electrode, 21–26

Faults and their elimination, 90–95
Filing of electrocardiograms and reports, 99–103
Films, processing of, 118
Fuse plate, 57

Galvanometer for phonocardiography, 113
for transistor-operated cardiographs, 71–74
for valve-operated cardiographs, 51–54
string, 3, 5, 42
Goldberger, augmented unipolar limb leads, 4, 25
Grishman's "cube", 125

Hearing, characteristics, importance for phonocardiography, 104
Heart, anatomical data, 12
atrio-ventricular system, 16
beat, electrical changes produced by, 10
blood supply, 16
conduction system, 16
impulse, formation site of, 16, 18
muscle cell, introduction of electrodes into, 40
excitation of, 10
direction of spread and recession, 11
physiological data, 13–16, 106, 107
position, effect on electrocardiogram, 33
sinu-atrial node, 16
sounds, first, 106, 107
fourth, 106, 107
historical development of, 4
intra-cardiac recording of, 114
recording of, 104–115. *See also* Phonocardiography
early work on, 5
second, 106, 107
third, 106, 107
timing of, 105
valves, 14, 106
His, bundle of, 16, 18
Historical development of electrocardiography, 3
of phonocardiography, 4
Hürthle, K., early work on phonocardiography, 5

Illuminating system of string electrocardiograph, 43
Indexing of electrocardiograms, 99–103
Indifferent electrode, 21–26
Interference, alternating current, 90–92
due to respiration, 94
elimination, 94
electromagnetic, 90
electrostatic, 90
eliminator for valve-operated cardiographs, 57
extraneous, 90–94
somatic, 93
elimination, 94
Intracavitary leads, 26

Jelly for electrode application, 77
Jugular venous pulse tracing, 106, 110
Junction, R-T (S-T) in electrocardiograms, 20
Junction transistor, 64
Junction-diode, 63

Leads, bipolar, 21
chest, 4, 21, 81
unipolar, 4, 24
connections, broken, 94
incorrect, to electrodes, effects, 81
to body, 86–89
intracavitary, 26
limb, bipolar, 21
unipolar, augmented, 25

Leads, limb, unipolar—*contd.*
effect of heart position on, 39
recording of, 25
œsophageal, 26
precordial, 21, 81
scalar, 120
construction from vectorcardiogram, 126
selector switch for string electrocardiograph, 44
for transistor-operated cardiograph, 74
for valve-operated cardiograph, 55
standard, 21, 25, 86
Lewis, T., early work on electrocardiogram, 4
on phonocardiogram, 5
Limb electrodes, application of, 79
fixing of, 79, 80
leads, bipolar, 21, 25, 86
effect of heart position on, 39
history of, 3, 21
unipolar, augmented, 25
introduction of, 4
recording of, 25

Mains connection for valve-operated cardiographs, 55
Mean electrical axis of excitation, 30
Microphones for phonocardiography, 111
fixing of, 112
intra-cardiac, 114
moving coil, 112
piezoelectric, 111
Mitral orifice, 12
Momentary electrical axis, 30
Monitor, electrocardiographic, 133
Mounting of electrocardiograms, 96–98
Murmurs, cardiac, recording of, 104
timing of, 105
Muscle strip, electrophysiology of, 7

Name index of electrocardiograms, 100

Œsophageal electrodes, 85
lead, 26
Operating-room cardioscope, 132, 133
Oscillograph, cathode-ray, for vectorcardiogram recording, 122, 123
Oscillographic recorders, 51

P wave, 18
in lead 3, 35
Pacemaker of the heart, 16
Paper, photographic processing of, 116–119
Patient, management of, 76
Pen recorder with heated stylus, 52
with special ink, 52
Phonocardiogram, recording of, 113
second, value of, 108
Phonocardiography, 104–115
amplifier for, 112
galvanometer for use with, 113
general considerations, 104
historical development, 4
importance of characteristics of human hearing in, 104
instrumental requirements, 111
intra-cardiac, 114
microphones for, 111
physiological considerations, 106
recorders, 113
special techniques, 114
time-reference records, 107
timing of, 105
Photographic records, developing and fixing, 116
printing of, 118
processing of, 116–119
equipment for, 116
washing and drying, 118
Physician's reports, filing of, 100
Precordial leads, 21. 81
Printed circuit, 67
Pulse, carotid, tracing of, 106, 110
jugular, tracing of, 106, 110
Purkinje fibres, 16

Q wave, 20
QRS complex, 20
in lead 3, 35

R wave, 20
R-T junction, 20
segment, 20
Record marking device, 57
Recorders, direct-writing, 51, 71, 85, 133
fine capillary with fluid jet, 53
for phonocardiography, 113
multichannel, 130
oscillographic, 51
pen with heated stylus, 52
pen with special ink, 52
stylus, heat control of, 56
tracing thickness control, 56
zero position adjustment, 56
Recording procedure, 85–89
Repolarisation, 7–10, 20
Reports, indexing and filing of, 99–103
Respiration, effect on electrocardiogram, 39
interference due to, 94

S wave, 20
S-T junction, 20
segment, 20
Scalar leads, 120
construction from vectorcardiogram, 126
Semiconductor diode, 63

Semiconductors, 62
Sinu-atrial node, 16, 18
Skin preparation for electrode application, 77
Somatic tremor, 93
  elimination, 94
Standardisation of electrocardiographs, 43, 55, 74
String electrocardiograph, 42–44
    components of, 42
    control panel, 43
    illuminating system, 43
    principle of operation, 44
    recording camera for, 43
    time-marker, 43
  galvanometer, 3–5, 42
Stylus heat control, 56
Switches, half sensitivity, 57
  selector, 44, 55, 74
  standardising, 43, 55, 74
Systole, 16

T wave, 20
    in lead 3, 39
Technician, attitude to patient, 76
Time-marker, 43
Torque motor for transistor-operated electrocardiograph, 71, 73
Tracing thickness control, 56
Transistor-operated cardiographs, 62–75
  amplifier for, 66
  components of, 66
  control panel, 74
  printed circuits in, 67
  recorders for, 71
  torque motor for, 73
  transistors for, 64
Transistors, 64
  mode of action, 64
Transmembrane action potential, 36, 40
Tricuspid orifice, 12

U wave, 21

***v* wave,** 110

Valve, amplifying, 48
  diode, 47
  mode of operation, 47
  physical construction, 45
  rectifier, 48
  triode, 48, 49
Valve-operated cardiographs, 45–61
    amplifier for, 50
    components of, 50
    control panel, 54
    earth connection, 58
    fuse plate, 57
    interference eliminator, 57
    mains connection for, 55
    muscle tremor suppression in, 58
    record marking device for, 57
    recorders for, 51
    variable speed control for chart drive, 58
Valves, cardiac, 14, 106
Variable speed control for chart drive, 58
Vector, 30, 120
  construction of, 30
  loops, 120
Vectorcardiogram, 120–128
  cathode-ray oscillograph for, 122, 123
  construction from bipolar limb leads, 127
  electrode placement for, 125
  recording of, 122
  spatial, 120, 128
Ventricles, cardiac, 12–18
Ventricular excitation, 18–20
  recovery, 20

Waller's work on electrocardiogram, 3
Wet-pad electrodes, 84
Wilson's central terminal, 23, 83, 86, 125
  tetrahedron, 125
  unipolar chest leads, 4, 23
Wolferth and Wood, re-introduction of chest leads, 4

***x* depression,** 110

depression, 110

Cardiographic Technique

Schott & Snell

Heinemann